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Mechanical Properties and Impact Damage Resistance of Composites Fabricated by Low Cost, Vacuum Assisted, Resin Transfer Molding

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Mechanical Properties and Impact Damage Resistance of Composites Fabricated by Low Cost, Vacuum Assisted, Resin Transfer Molding

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ABSTRACT

Fabric-reinforced laminates made by SCRIMP (Seemann Composites Resin Infusion Molding Process) were tested in compression, tension, flexure, short beam shear, and impact. A global study of the properties of SCRIMP panels was the goal of this program. Four vinyl esters, one polyester, and two epoxies were tested, as were seven different styles of E-glass fabric. The properties of E-glass fabrics were compared with those of carbon, Kevlar, and Spectra fabrics, and with the hybrids E-glass:carbon, E-glass:Kevlar, and E-glass:Spectra. Composite properties increased with resin modulus, provided the resin failure strain was above a critical (undetermined) minimum value. Light woven roving and textile fabrics had somewhat better properties than coarser woven rovings, and glass was the overall best performer based on cost, strength and impact resistance. An E-glass:Kevlar hybrid was identified which had significant weight savings but comparable properties to E-glass.

ADMINISTRATIVE INFORMATION

The work described herein was conducted to support a Balanced Technology Initiative for an Advanced Seal Delivery Vehicle. The Program Manager was Code 06Z of the Naval Sea System Command. The Technical Design Agent was Code 2310 of the Coastal Systems Station. This work was sponsored initially under Carderock Division, Naval Surface Warfare Center (CDNSWC) work unit 1-1720-221, and was completed as a Ship and Submarine Materials Block Program under CDNSWC work unit 1-2802-602.

INTRODUCTION

Composite panels were fabricated using SCRIMP[1] (Seemann Composites Resin Infusion Molding Process). The results reported herein represent an initial database on SCRIMP. Static mechanical properties and impact damage resistance were determined for a wide variety of material systems. The study included the effect of resin, style of E-glass fabric, and reinforcing fiber. Also tested were hybrids of E-glass with carbon, Kevlar, and Spectra.

MATERIALS EVALUATED

The purpose of this study was to determine the range in properties which can be achieved with SCRIMP. The materials were varied as broadly as possible. The survey was conducted by first comparing the properties of 6 resins (4 vinyl esters, 1 epoxy, and 1 polyester) reinforced with the same 24 oz. woven roving. A single resin was then selected, and used to study the effect of glass fabric style (7 total) and reinforcing fiber (glass, carbon, Kevlar, and Spectra). The best overall glass fabric was then used to determine the properties of hybrids.

RESINS

The goal here was to determine the effect of the resin on composite properties, where the candidates are polyester, vinyl ester, and RTM-grade epoxies. Given that there are several hundred candidates, we had to select representatives of each of the three resin types. The possibility exists that generalizations drawn from this study concerning the effect of resin on composite properties are invalid due to the limited number of resins evaluated.

A description of the resins tested is given in Table 1. The data which appears in Table 1 were taken from manufacturer's data sheets. Data were not available for the two epoxies evaluated. However, Tactix 123:Millamine 5260 is essentially identical to Tactix 123:H31[2], the data for which appears in Table 1. In addition, given the apparent similarity between Tactix 123 and the Shell Chemical resin, Epon 9405, the stiffness and failure strain are expected to be equivalent to the Tactix 123:Millamine 5260 resin.

GLASS FABRIC STYLE

The 7 styles of E-glass fabric tested here are listed and described in Table 2. There are 5 woven rovings, a stitched biaxial, and a woven yarn. The "woven roving" in Table 2 and Figures

Table 1. **The resins evaluated in this study. Values of Young's modulus (E) are in ksi, and failure strains (ϵ) are %.**

Resin	E	ϵ	Description
Derakane 510A	500	6	Brominated vinyl ester
Derakane 8084	460	10	Rubber-toughened vinyl ester
CoRezyn 8510	NA	10	Vinyl ester toughened without rubber
CoRezyn 8520	360	20	Vinyl ester toughened without rubber
Tactix 123	430	6	RTM epoxy, cured with Millamine 5260
Epon 9405	430	6	RTM epoxy, cured with Millamine 5260
Cargill 8472	540	2	1:1 isothalic polyester

Table 2. **The glass fabrics tested in this study. The "Mils" column is mils/ply in the laminate.**

Designation	Oz/Yd^2	Mils	Weave	Roving
10 oz. Twill	9.6	10	3X1	FGI, 1200 yds/lb
24 oz. Twill	24	26	3X1	Cert'teed 625, 225 yds/lb
Woven Roving (WR)	24	24	Plain	Cert'teed 625, 225 yds/lb
Chomarat	24	31	2X2	
DF 1400	40	42	2X1	Spun roving in fill
Stitched Biaxial	19.4	26	-	330/617 yd/lb (warp/fill)
Style 7781	8.5	9.5	8HS	Hexcell F72, 7500 yds/lb

2-11 is so-designated because it is the industry standard, a 24 ounce plain weave. Five of the fabrics are shown in Figure 1 for comparison.

The first three woven rovings in Table 2 were made at Seemann Composites. The fourth, the Chomarat fabric, is a French material which has been given a mechanical surface treatment (see Figure 1) for improved resistance to delamination. The fifth woven roving, DF 1400, is the fabric

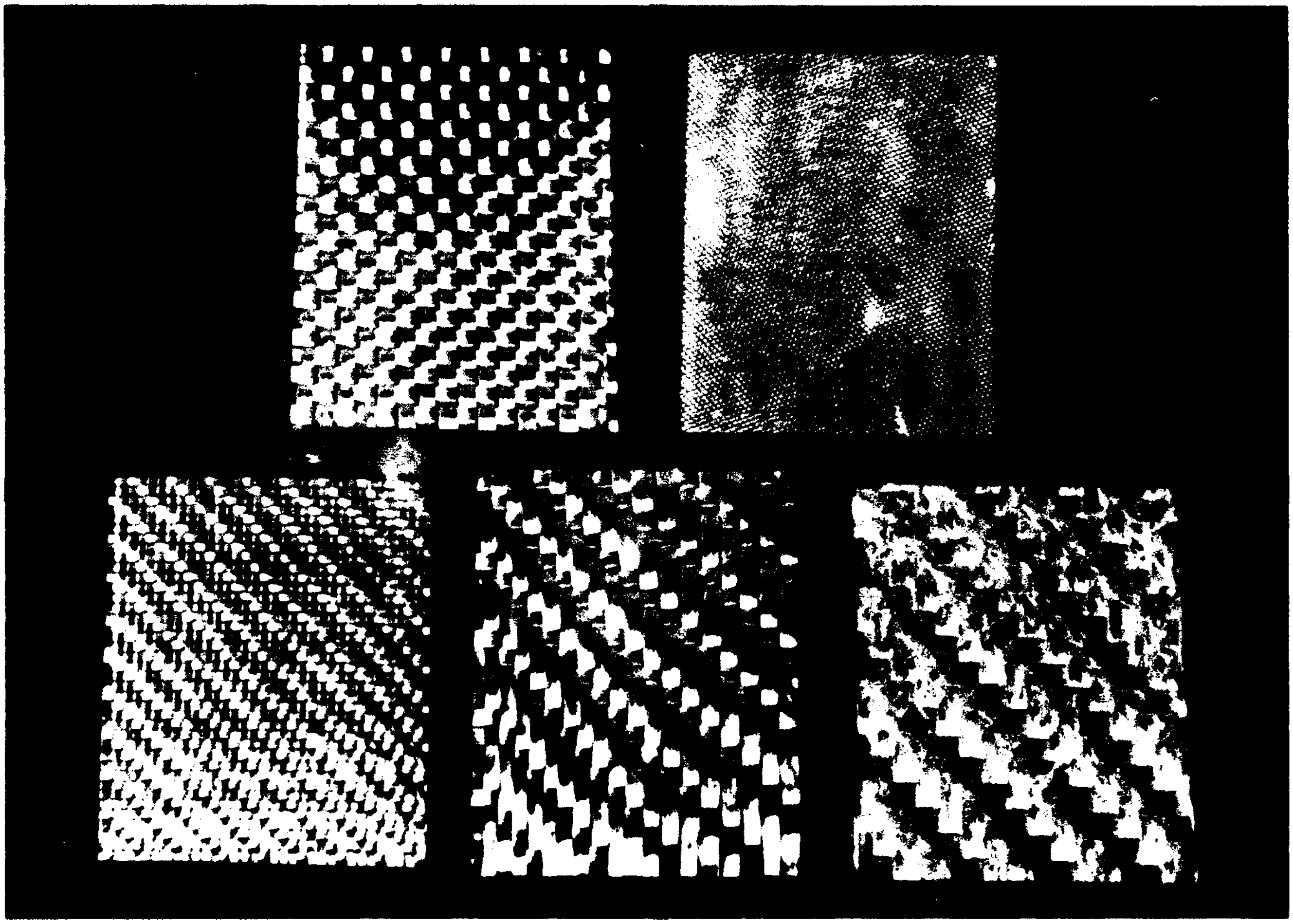


Fig. 1. The glass fabrics shown are (top row, left to right) the 24 oz. woven roving and Style 7781, and (bottom row) the 10 Twill, 24 Twill, and the Chomarat fabric.

used in the MHC 51 class for the hull, deck, and bulkheads[3]. It was made by Certainteed and is composed of spun roving in the fill direction. It is the only woven roving tested here with an unbalanced composition in warp and fill. It is 25 oz/yd^2 in the fill direction, and 15 oz/yd^2 in the warp. For this reason, properties of laminates containing this fabric were measured in both the warp and fill direction.

The stitched biaxial fabric is Hexcel CD180. It was included to evaluate the effect of uncrimped rovings. Also included in the testing was a woven yarn, or textile fabric, Style 7781, a Hexcel material finished with F72, a polyester and vinyl ester compatible coupling agent.

FIBERS

Carbon, Kevlar, and Spectra fabrics were evaluated for comparison with E-glass. The materials used in this study are described in Table 3.

Table 3. The Carbon, Kevlar, and Spectra fabrics evaluated. The "Mils/Ply" values were measured in the laminate.

Fiber	Style	Oz/yd^2	Mils/Ply	Weave	Tow
Carbon	1059	15.5	22	5HS	12K AS4W
Carbon	1029	10.9	16	8HS	3K XASg
Carbon	1029	10.9	16	8HS	3K T300 UC309
Carbon	1030	10.2	15	5HS	6K (fiber unknown)
Kevlar	285	5.0	13	Crowfoot	K49, 1140 Denier
Kevlar	900	9.0	17	5HS	K49, 2160 Denier
Spectra	985	5.5	10	8HS	S1000, 650 Denier

HYBRID REINFORCEMENT

Six hybrid composites were evaluated, as described in Table 4. They all contained glass, specifically the 10 oz. twill, along with carbon, Kevlar, or Spectra. The plies were arranged in a

Table 4. The hybrids evaluated in this study. The thickness ratios were calculated from measured panel thickness. Values of % (by volume) glass are nominal.

Hybrid	Center Plys	Thickness Ratio	% Glass
Glass:Carbon:Glass	Carbon 1059	1:2:1	50
Glass:Carbon:Glass	Carbon 1029	1:2:1	50
Glass:Kevlar:Glass	Kevlar 900	1:1.3:1	60
Glass:Kevlar:Glass	Kevlar 900	1:1.8:1	50
Glass:Kevlar:Glass	Kevlar 285	1:2.8:1	40
Glass:Spectra:Glass	Spectra 985	1:1.3:1	60

sandwich configuration with the glass layers on the outside. The "thickness ratio" in Table 4 was derived from the panel thickness, and using the value of 10 mils/ply for the glass. The "% glass" column are the targeted values of % by volume of glass laminate, i.e., 40% glass describes a hybrid composed of 40% glass laminate, 60% Kevlar laminate.

COMPOSITE FABRICATION

All laminates weie made by resin transfer molding at Seemann Composites, Inc. The panels were 2' x 1', and about 0.15" thick. The layup was all warps parallel. The polyester and vinyl ester panels were cured at room temperature with MEKP (1.25%) as the catalyst, accelerated with CoNap (0.3%). These panels were post-cured at 140 °F for 8 hours. The epoxy composites were fabricated at about 140 °F, and cured at 250 °F for 3 hours.

EVALUATION PROCEDURE

The composites were tested in compression, tension, flexure, short beam shear, and impact. Some materials were tested for in-plane shear properties. Except where indicated, tensile, compressive, and flexural properties were determined in the warp direction. Samples of the glass panels were tested for fiber volume fraction and void content.

FIBER CONTENT AND PERCENT VOIDS

Fiber weight percent and void volume fraction were determined on the glass panels from specific gravity measurements (ASTM D792) and ignition loss (ASTM D2584).

STRENGTH

Compression

Compression testing was done with the *ASTM D695 meth*odology. These "dogbone" specimens are end-loaded and side-supported, with nominal dimensions of 3.13" overall length and 0.5" wide in the gage section. The dogbone shapes are made by grinding with a Tensilcut router and a template. Failure usually occurred in the gage, but occasionally the samples would crush at an end.

Tension

Tensile strength was measured using the ASTM D638 methodology. These are dogbones machined from 6" long, 3/4" wide coupons using a Tensilcut router and a template. The final widths are nominally 1/2". Tensile strains were measured with an extensometer, and Young's moduli determined by linear regression of the initial portion of the stress-stain curve.

Flexure

Flexural strength and modulus were measured with the ASTM D790 procedure (three point bending.) The sample dimensions were about 5.5" long and 0.5" wide. The span used was 4.5".

Short Beam Shear

ASTM D2344 was used to measure SBS strength. A sample width of 0.5" was used for all tests, and the span-to-depth ratio was kept approximately at 5.

IMPACT

Impact testing was done with a Dynatup Model 8200 drop tower. The drop weight was 15.2 lbs., and the impactor was a hemi-spherical tup with a diameter of 0.5". Impact specimens were 6"x4" panels clamped over a 5"x3" opening. Four spring-loaded clamps secure the specimen over the rectangular hole, two along each of the 6" sides of the panels.

The tests were done at levels of 1000, 2000, 3000, 3500, 4000, 4500, and 5000 in.lbs./in, or until penetration. Impact "level" is the energy in inch-pounds divided by the sample thickness in inches. The data is presented by plotting the area of the damage zone vs. impact level, the highest level being that required for penetration. Damage area was quantified by measuring four diameters (D) through the impact damage zone (at 0°, 90°, and ±45° with respect to the 6" dimension), taking the average of these four numbers and computing the area $\pi D^2_a/4$. For the glass panels, the damage areas were identified visually. The Kevlar and carbon reinforced laminates were ultrasonically inspected to determine damage zone.

RESULTS AND DISCUSSION

All the data taken in this study is recorded in the Appendix. It will be discussed in four sections: effect of resin, effect of glass fabric style, effect of fiber, and effect of hybrid reinforcement.

FIBER CONTENT AND PERCENT VOIDS

Fiber contents for the seven glass laminates are compared in Figure 2. Panels reinforced with the 24 oz. plain weave and the two twills had the highest weight percent fiber, more than 70%.

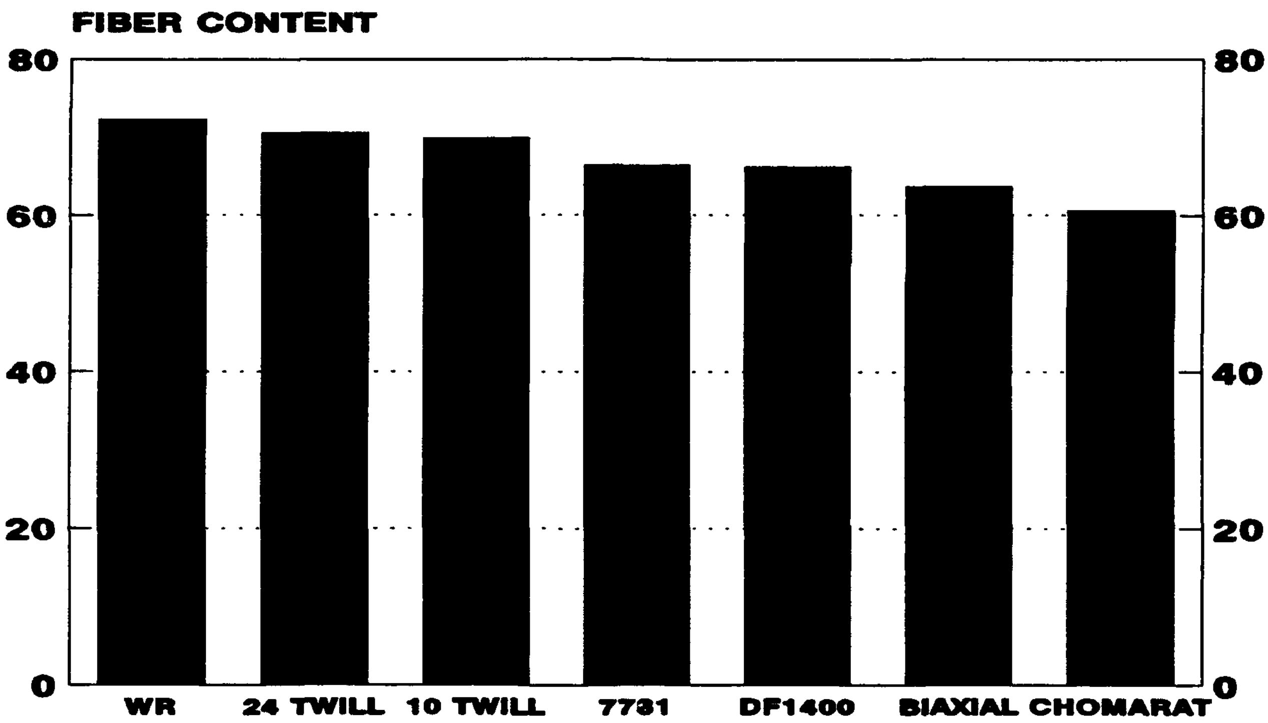


Fig. 2. The weight % glass of the glass fabric reinforced laminates tested in this study.

Panels made with Style 7781, the stitched biaxial, the Chomarat fabric, and DF1400 contained somewhat less fiber. The Chomarat and DF1400 materials presumably had lower fiber contents because of the bulkiness which results from tufted or spun roving. The biaxial had lower fiber

contents because of the spacing between rovings. It is unclear why the textile fabric did not impregnate to the high fiber content that SCRIMP provides to woven roving. All panels were void free except the stitched biaxial, which had about 1% voids. The intimate contact between rovings caused by the stitching operation possibly led to the nominal void content in this material.

EFFECT OF RESIN

Six panels were procured from Seemann Composites, composed of different resins but all having 24 oz. plain weave woven roving reinforcement. The effect of resin on compression, tension, flexure, short beam shear, and impact damage is shown in Figures 3-7. It is clear from the data that resin selection significantly effects composite properties, and that variations in both resin modulus and failure strain caused the observed differences.

Strength

Composite compression strength (Figure 3) increases with resin modulus for these fabric-reinforced materials, a trend which was first reported for carbon/epoxy laminates from prepreg tape[4]. The trend is also indicated in the data for unidirectional glass-reinforced vinyl ester[5,6]. Flexural strength (Figure 4) also increases with resin modulus, as it should, given that samples deformed in flexure usually fail in compression.

The rule that composite compression (and flexural) strength is proportional to resin stiffness is violated for the polyester. It can be postulated that the low failure strain of the polyester precluded the composite from realizing the compression strength potential provided by the resin modulus. Future work is planned to investigate polyesters with higher tensile failure strain (which is achieved at the expense of Young's modulus). Composite tensile strength (Figure 5) was not controlled by resin properties, as is usually reported[4,5,6].

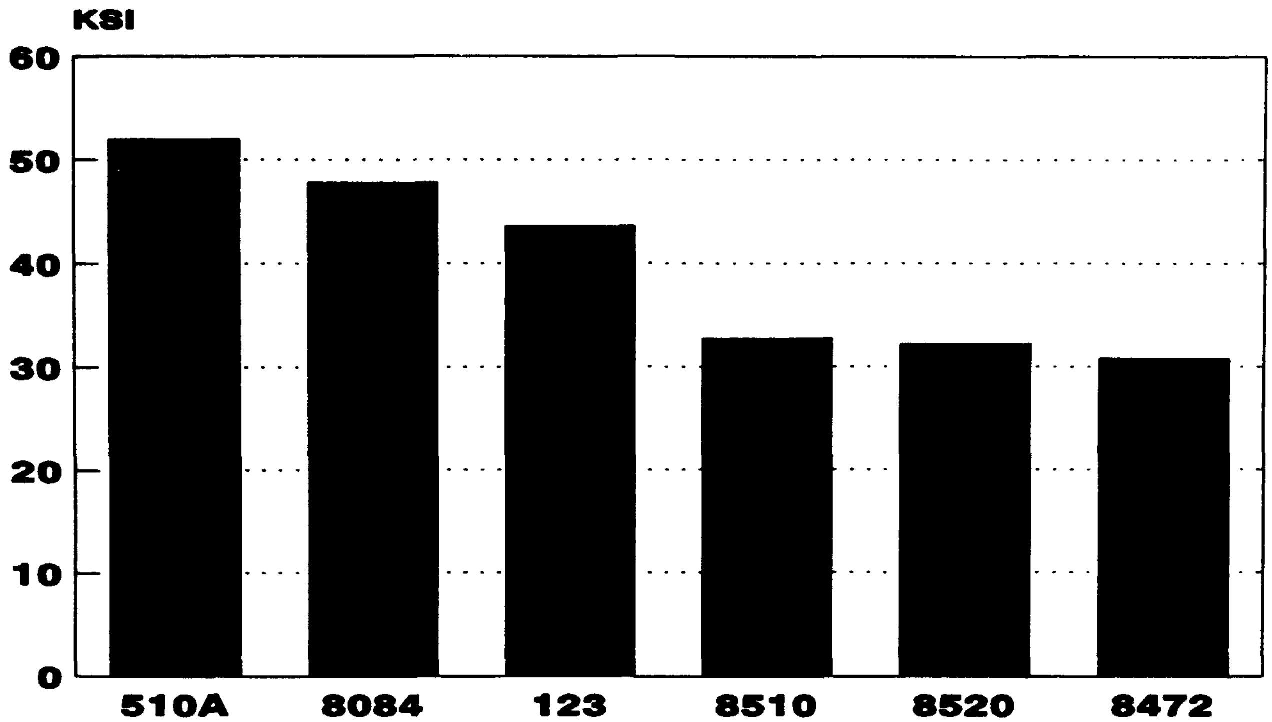


Fig. 3. The effect of resin on compression strength (ksi) of laminates reinforced with 24 oz. woven roving.

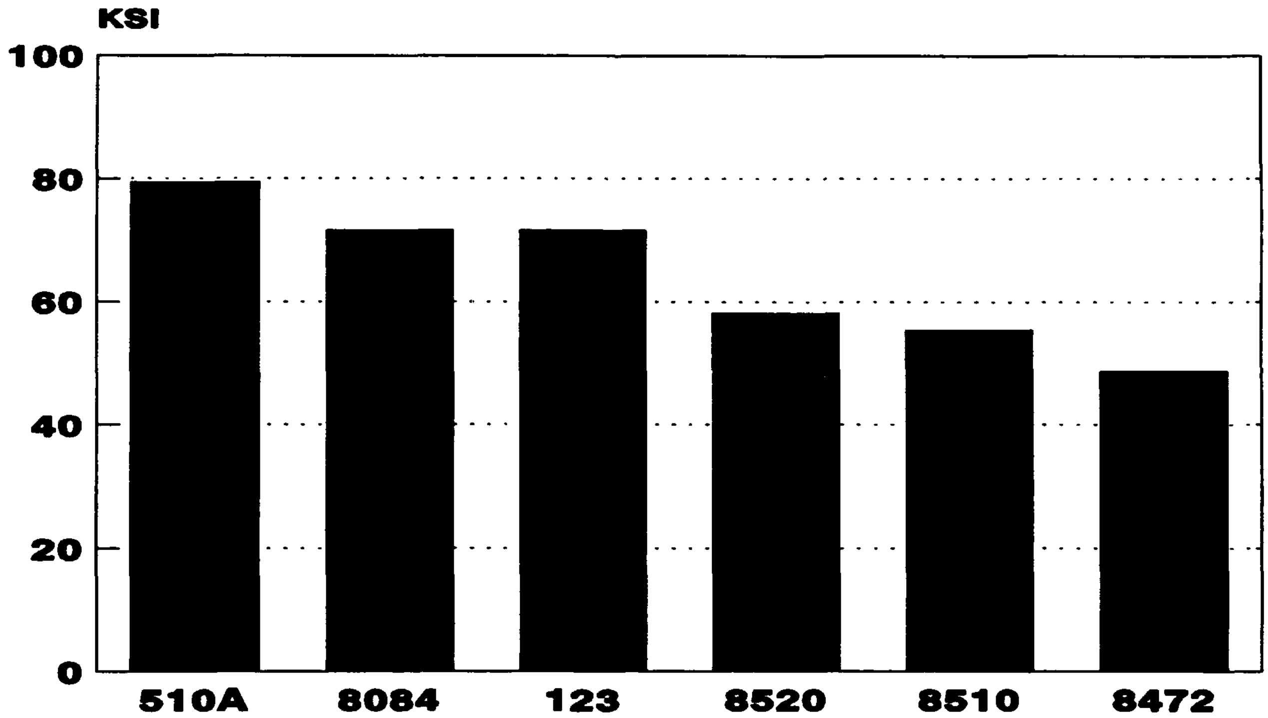


Fig. 4. The effect of resin on flexural strength (ksi) of laminates reinforced with 24 oz. woven roving.

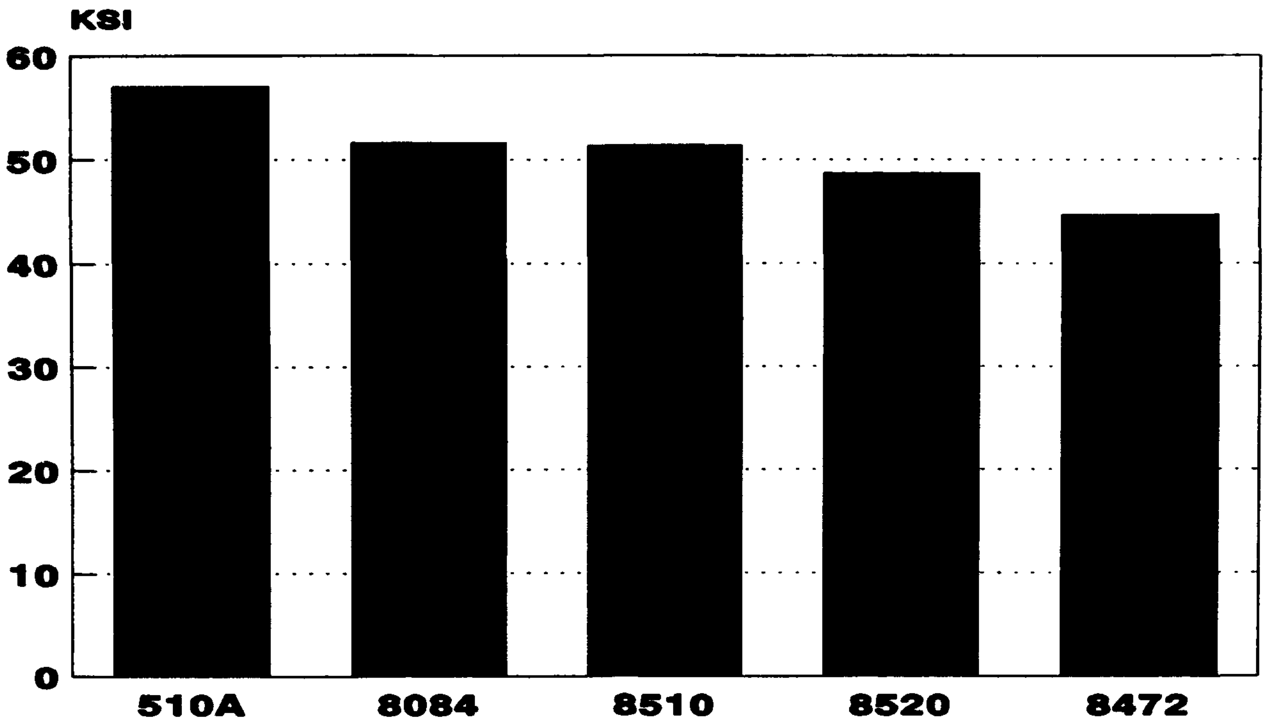


Fig. 5. The effect of resin on tensile strength (ksi) of laminates reinforced with 24 oz. woven roving.

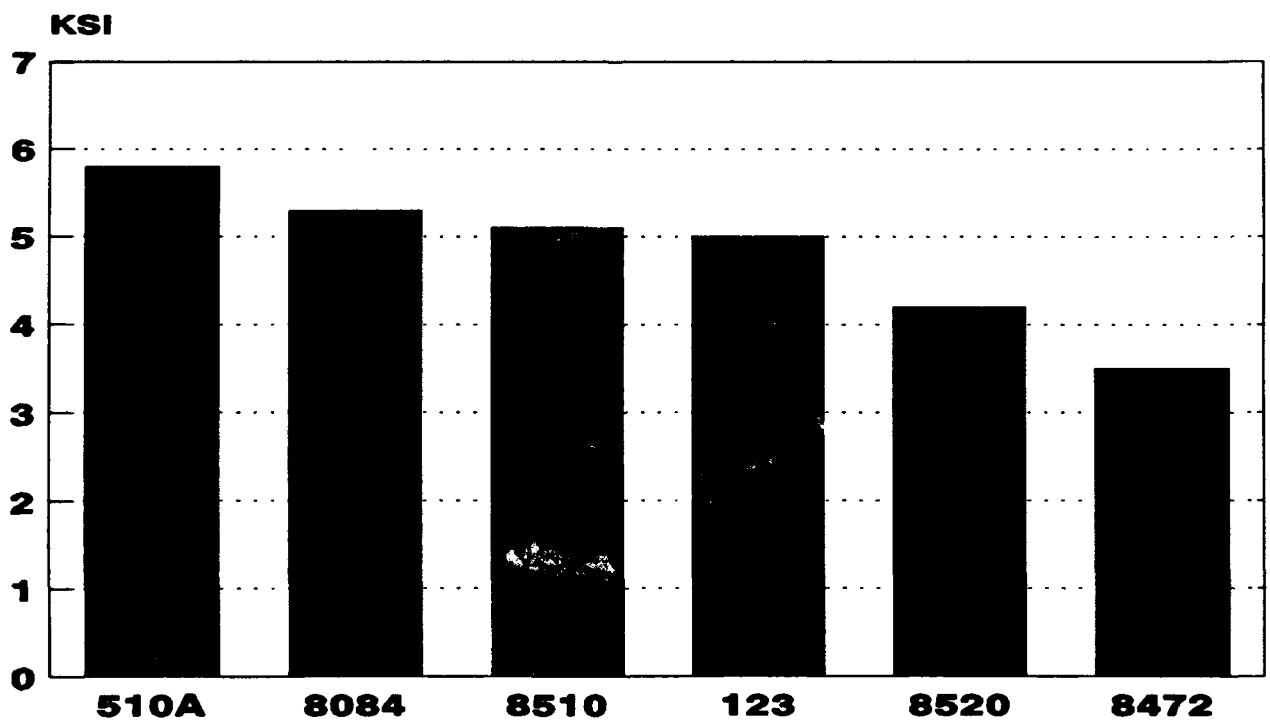


Fig. 6. The effect of resin on short beam shear strength (ksi) of laminates reinforced with 24 oz. woven roving.

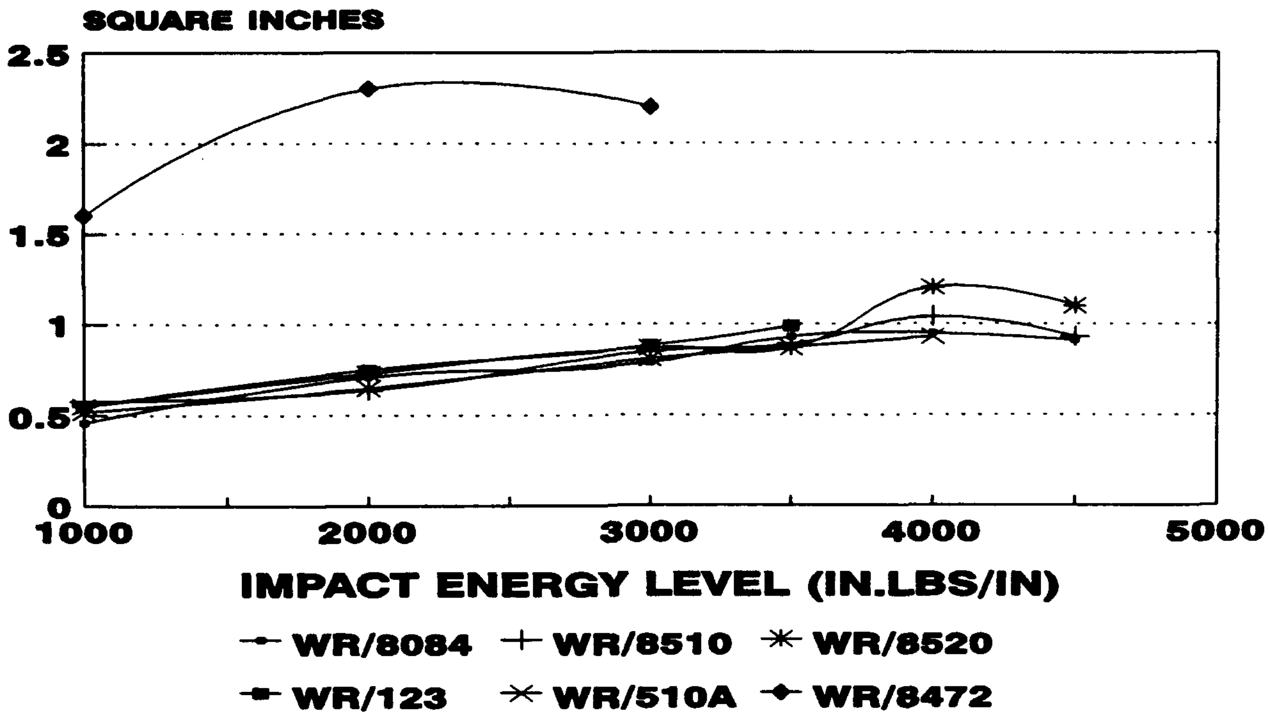


Fig. 7. **The effect of resin on impact damage area (square inches) of laminates reinforced with 24 oz. woven roving.**

Impact Resistance

The impact damage areas are given in Figure 7. It was surprising to note that the resistance to impact damage of laminates having glass fabric reinforcement was relatively insensitive to resin failure strain. Laminates whose resin failure strain was 6% (epoxy) did not have larger damage areas than laminates composed of resins with 20% strain. Again, the polyester does not follow this trend. Evidently the very low resin failure strain (2%) is below some critical value, which precludes realization of the full deflection capable by the glass.

Summary

It should be realized that the scope of this resin evaluation was limited to basic mechanical properties and a few resins with diverse characteristics. Under investigation was the effect of resin

stiffness and failure strain. It was found that composite properties increase with Young's modulus of the resin, as long as the resin failure strain is above some critical (undetermined) value. It was also found that increases in resin failure strain above this critical value do not improve composite impact damage resistance.

This study was not an evaluation of the relative performance of the various manufacturers candidate resins. Interplastics CoRezyn 8510 and 8520 were chosen for their failure strains, which are the highest currently available. Although the formulated resin ductility of 8510 and 8520 did not help impact damage resistance (and impaired static strength due to the accompanying low stiffness), applications which require fatigue resistance or fracture toughness may benefit from the high resin strain. Interplastics has a large number of vinyl ester resins, including the high modulus CoRezyn 8440, which would have performed as well as any in the study if the conclusions reached herein are valid.

EFFECT OF GLASS FABRIC STYLE

Panels made with the seven E-glass fabrics selected for evaluation were procured from Seemann Composites Inc., with Derakane 8084 resin. Comparison of the static strength and impact damage resistance appears in Figures 8-12.

Strength

There was a surprisingly large effect of glass fabric selection on the strength of the laminates, which could not in general be explained by fiber or void contents. The glass fabrics with the best overall properties were the 10 oz. twill and 7781.

The 10 oz. twill and the textile fabric (7781) were the strongest in compression. As can be seen in Figure 1 and Table 2, these are the two materials with the lightest (least coarse) input

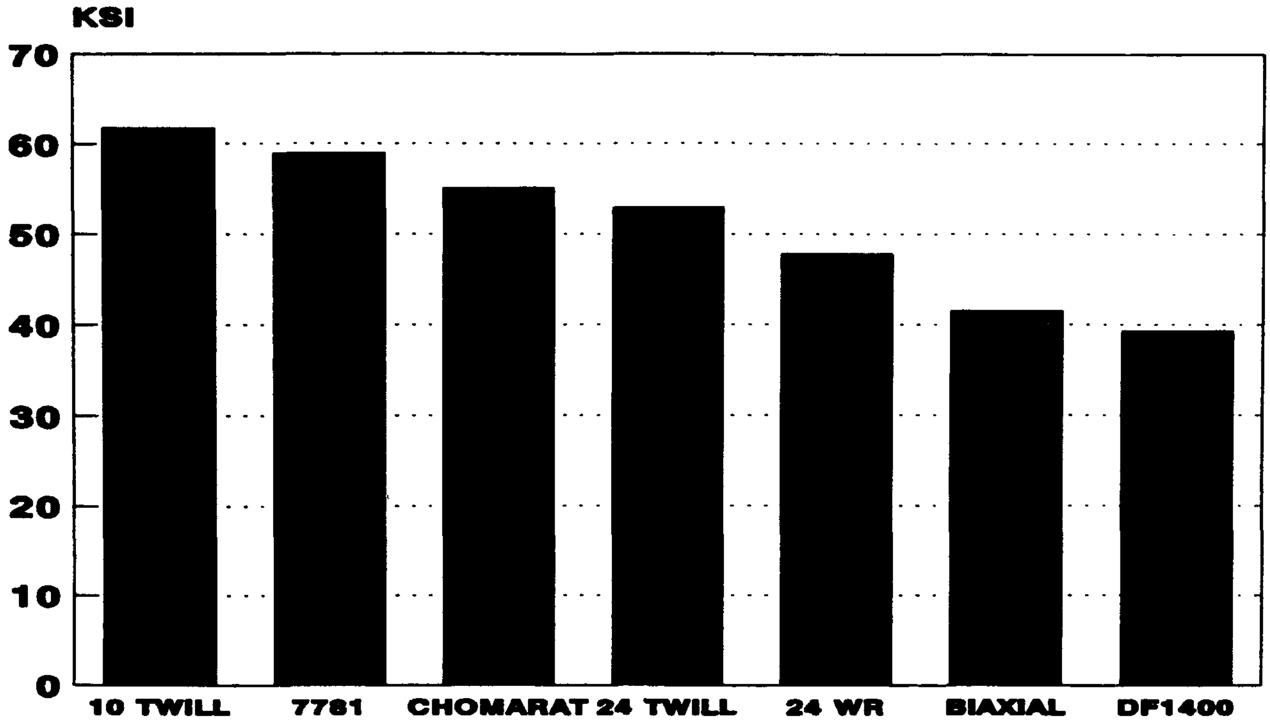


Fig. 8. **The effect of glass fabric on compression strength. The resin is Derakane 8084 throughout. DF 1400 was tested in the fill direction.**

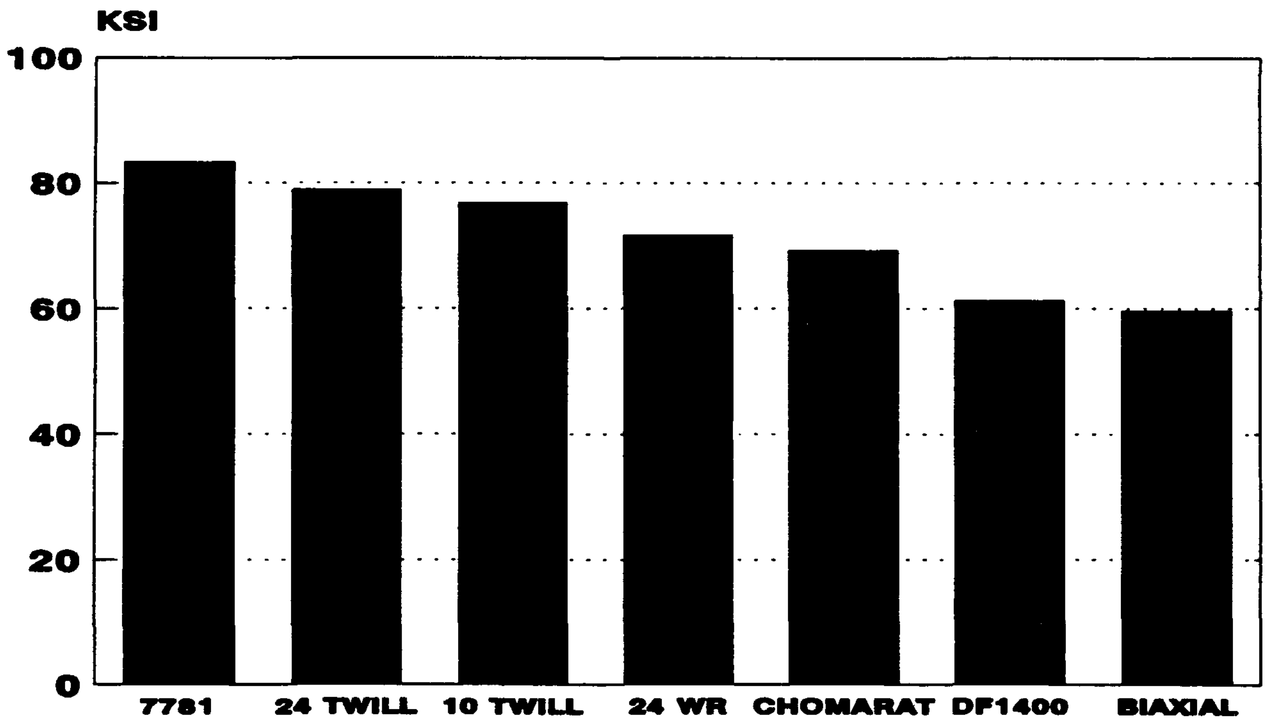


Fig. 9. **The effect of glass fabric on flexural strength. The resin is Derakane 8084 throughout. DF 1400 was tested in the fill direction.**

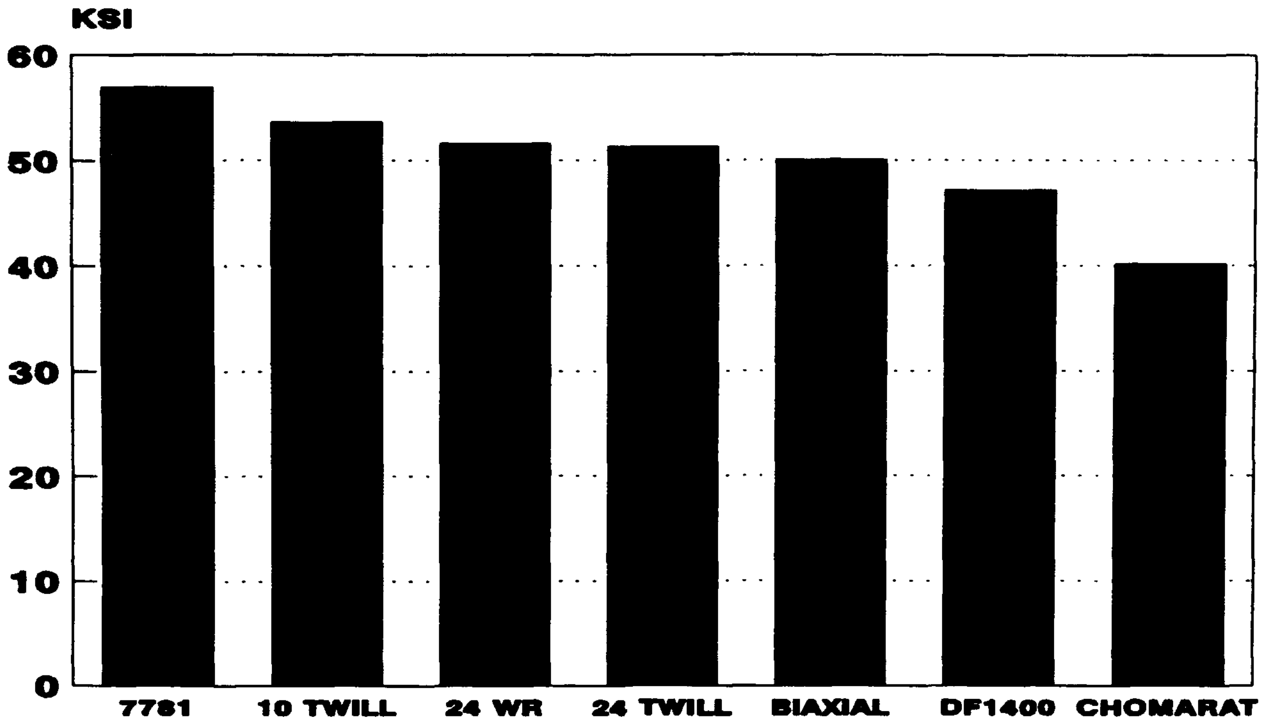


Fig. 10. The effect of glass fabric on tensile strength. The resin is Derakane 8084 throughout. DF 1400 was tested in the fill direction.

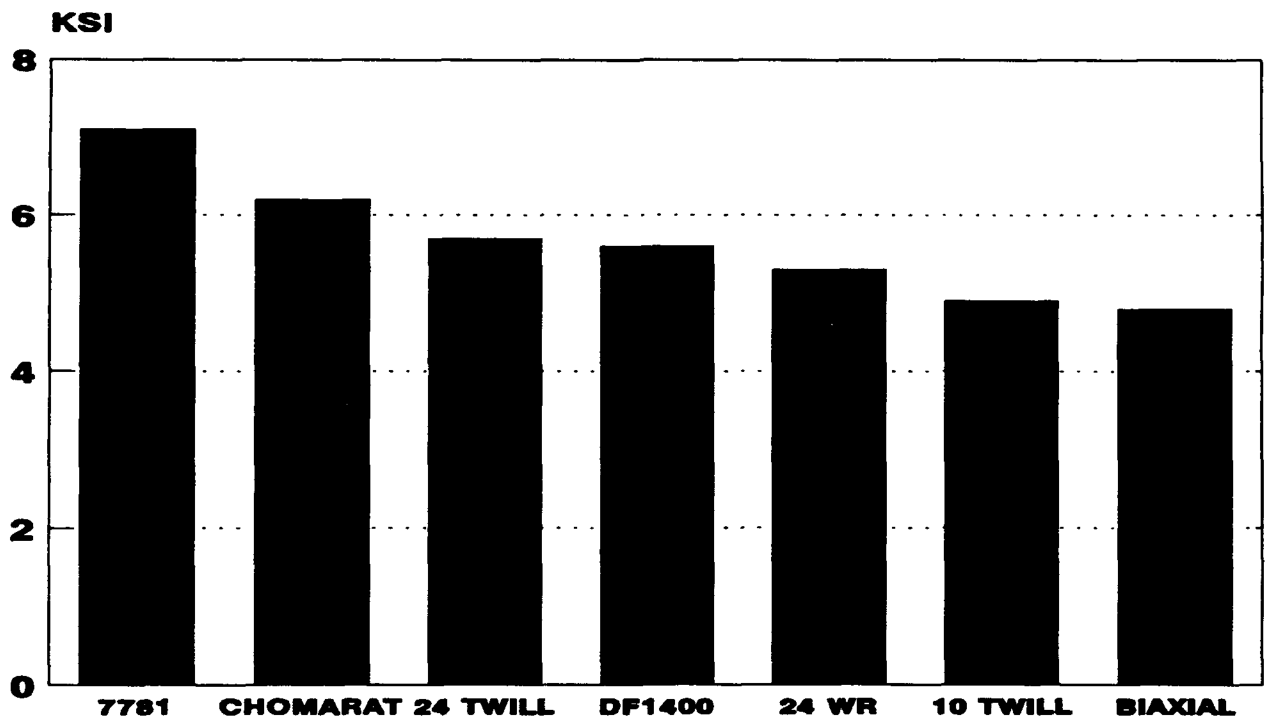


Fig. 11. The effect of glass fabric on SBS strength. The resin is Derakane 8084 throughout. DF 1400 was tested in the fill direction.

rovings. This characteristic would minimize the displacement, or amplitude, of the rovings at each crossover. An initial study of compression strength vs. amplitude of displacement is shown in Figure 13, where the trend appears to agree with this argument.

A larger compressive strength was expected from the stitched biaxial fabric. As indicated in Figure 13, the rovings in knitted fabric are not straight, but have a relatively small periodic displacement from the stitch. The low compression and flexural strength values may be attributable to the lower fiber content in this material, which appears to result from the relatively large spacings between rovings. It should be noted that fabrics of uncrimped rovings such as the stitched biaxial tested here possibly have superior fatigue resistance compared to woven forms of glass. There is anecdotal evidence for this[7].

Impact Resistance

It can be seen in Figure 12 that the glass fabric style had a measurable effect on impact damage area. A generalization can be made that the finer weaves had superior ability for impact damage containment. Both glass twills had a 3x1 construction, but the impact resistance of the 10 oz. fabric, composed of 1200 yd./lb. rovings, was somewhat better than the 24 oz. material with 225 yd./lb. rovings. It also appears that a plain weave has superior ability at impact damage containment than a twill, which can be seen by comparing the performances of the 24 oz. plain weave (WR) with the 24 oz. twill in Figure 12. The stitched biaxial had relatively large impact damage areas, but it required high levels to penetrate.

The tufted rovings of the Chomarat fabric apparently were useful for impact resistance, possibly by increasing delamination resistance. In contrast, there was no evidence that the spun roving in DF 1400 improved delamination resistance. We wish to note that these fabrics were all evaluated with a high strain-to-failure resin. The spun roving in DF 1400 may improve impact

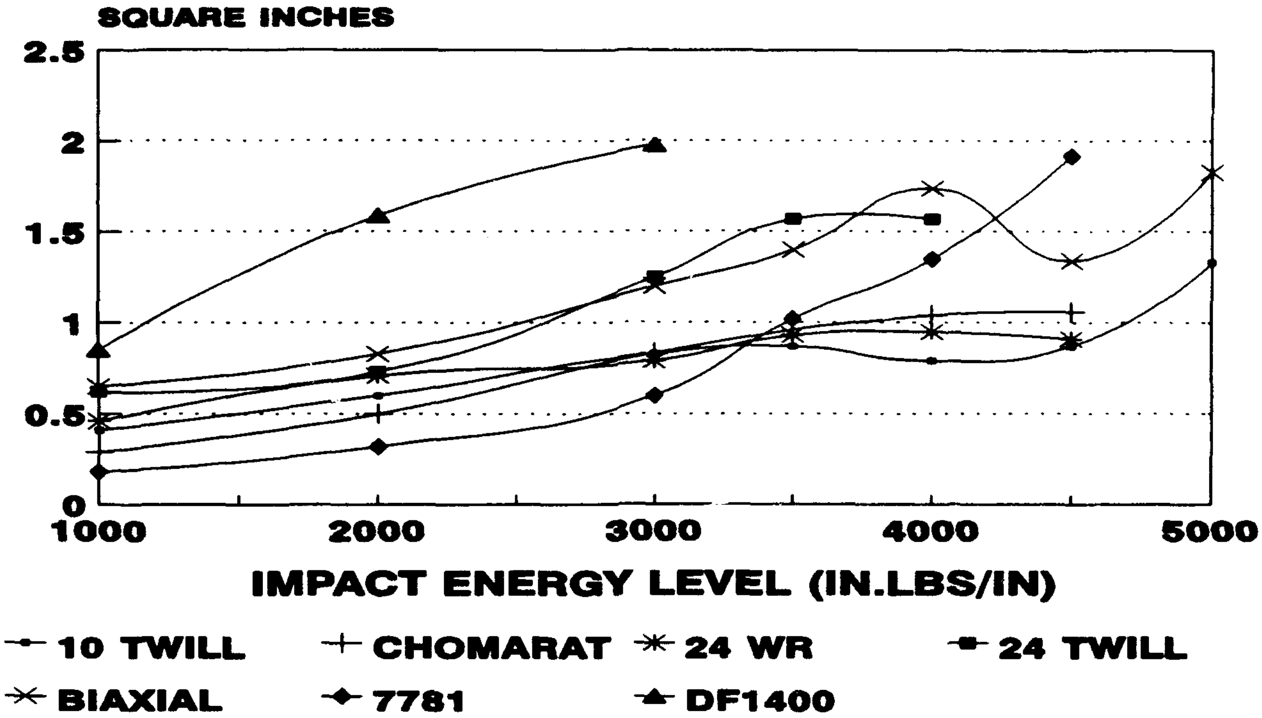


Fig. 12. **The effect of glass fabric on impact damage area. The resin is Derakane 8084 throughout.**

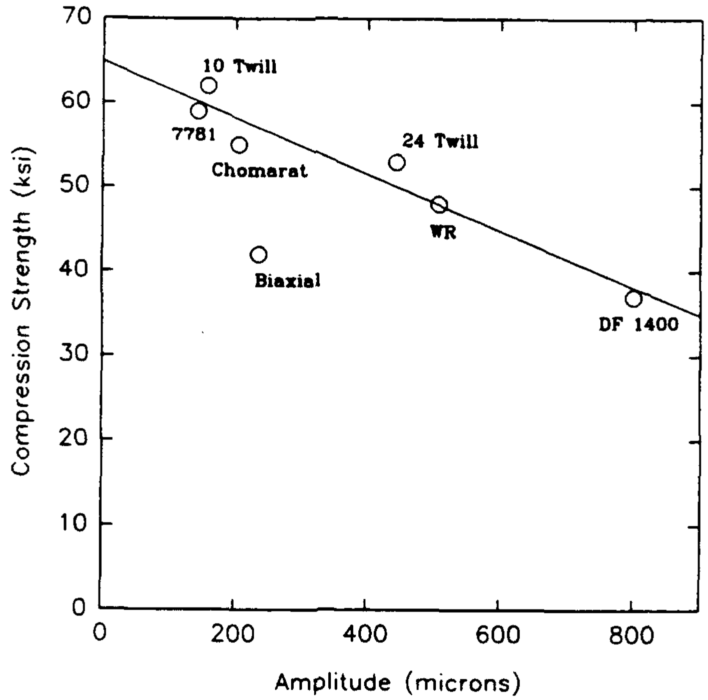


Fig. 13. **The compression strength of the glass fabrics correlates with the amplitude of distortion of the rovings caused by the crossover in the weave.**

damage resistance when a resin with a relatively low failure strain is used.

Woven Roving vs. Woven Yarn

There are many significant differences between woven roving and woven yarn. It can be stated that in general, material selection based on cost/property tradeoffs favor v ɔven yarn (such as

Table 5. A comparison of the approximate cost per pound, flexural and compression strengths (ksi), and inputs used in three glass fabrics evaluated.

Fabric	$/lb	Flexural Strength	Compressive Strength	Fabric Inputs
24 oz Plain Weave	1.25	71.9	47.8	225 yd/lb roving
10 oz Twill	2.5	76.7	61.7	1200 yd/lb roving
Style 7781	5.0	83.6	58.1	7500 yd/lb yarn

Style 7781) for properties and woven roving for cost. Our data also indicates that the light (10 oz/yd^2 twill) woven roving has properties comparable to woven yarn but at much reduced cost. These cost/property tradeoffs are summarized in Table 5.

Woven yarns, also called textile fabrics, are relatively expensive compared to woven roving because there are many steps required for their production and loom throughputs are low. (Also, the glass fibers in yarn have diameters from 7-10 microns, whereas filament diameters in roving are usually 17-19 microns.) Immediately after the molten glass is extruded through the bushing and air cooled, the filaments so-formed are sized with a protective lubricant and collected into strands of various yield, such as 7,500, 15,000, and 22,500 yards/pound. The individua! strands are then twisted to some specified number of turns per inch (in some cases two or more strands are twisted

together) to form yarns. Some fabrics, like Style 7781, are woven from single, twisted yarns, but many are composed of two or more yarns which are plied together. Yarns are plied by twisting them together, where the twist occurs in the direction opposite to that in the yarn so that the plied yarn does not take on a helical shape. The yarn is then woven into a fabric with the specified pattern. After the weaving operation, the fabric is heat cleaned to remove the size applied by the yarn manufacturer. The heat cleaned fabric is then coated with a "finish" for glass/resin adhesion. Finishes are usually resin specific silane coupling agents: glycidyl- or amine-terminated silanes for epoxy resins and vinyl-terminated silanes for polyesters and vinyl esters.

In contrast, woven rovings are made with fewer steps. After the filaments are extruded they are coated with a size, composed of a resin compatible film former (usually a liquid or solid epoxy), coupling agents, lubricants, emulsifiers, etc.[8] The filaments are then gathered into a bundle called a sliver, and the desired number of slivers are in turn assembled (without twisting) into a roving, which are used as inputs for the weaving operation. More commonly, the slivers themselves are used as inputs, usually called single end rovings. The most commonly used single end rovings have yields of 217-250 yds/lb, but they are available in higher yields (such as the 1200 yds/lb roving used to make the 10 oz. twill evaluated in this study). The sizes for rovings are usually tricompatible, meaning they couple glass to polyesters, vinyl esters, and epoxies.

The properties of composites reinforced with textile fabrics are in general somewhat better than those with woven roving, which may be due to the finer inputs and resulting smaller displacements of the former, as shown in Figure 13. It should be noted, however, that the twisting of glass strands to make yarns, the rapid weaving operation, and the subsequent handling of the woven yarns, damage the glass. This fiber damage almost always results in lower tensile strength than compressive strength for textile fabric laminates. In most composites, the tensile strength exceeds the compressive strength.

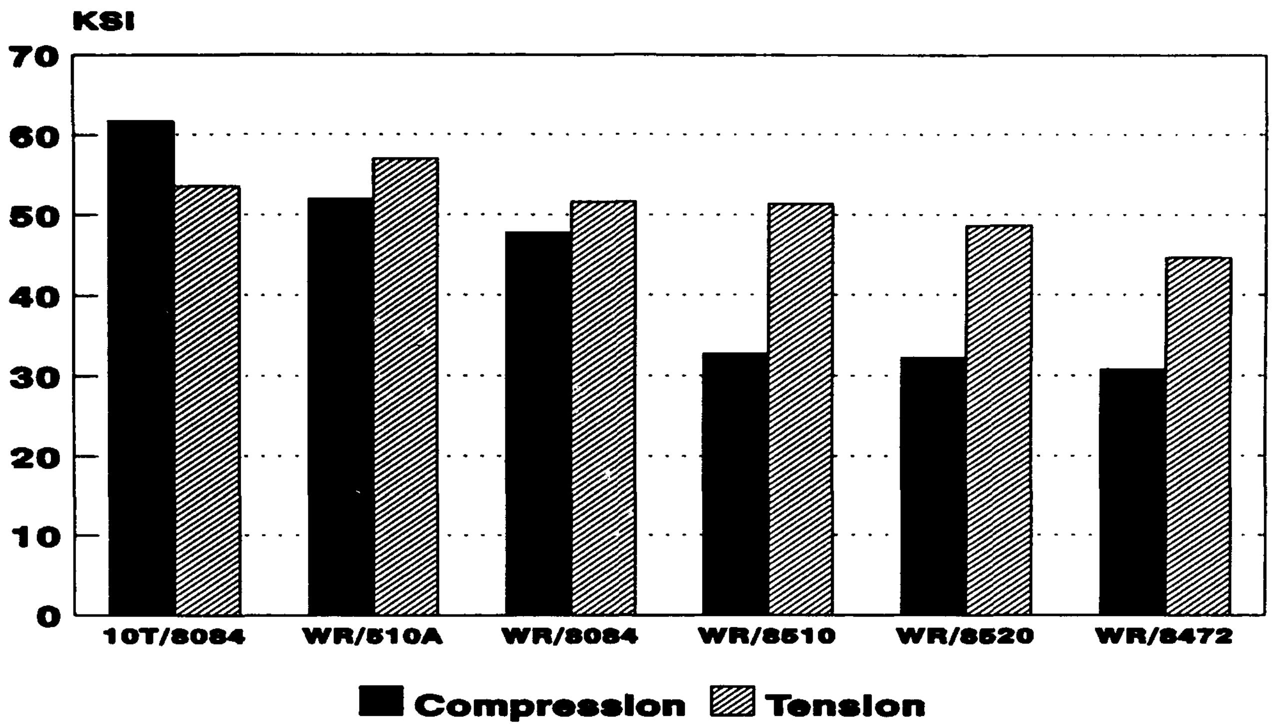


Fig. 14. A comparison of tensile strength with compressive strength of woven roving reinforced laminates.

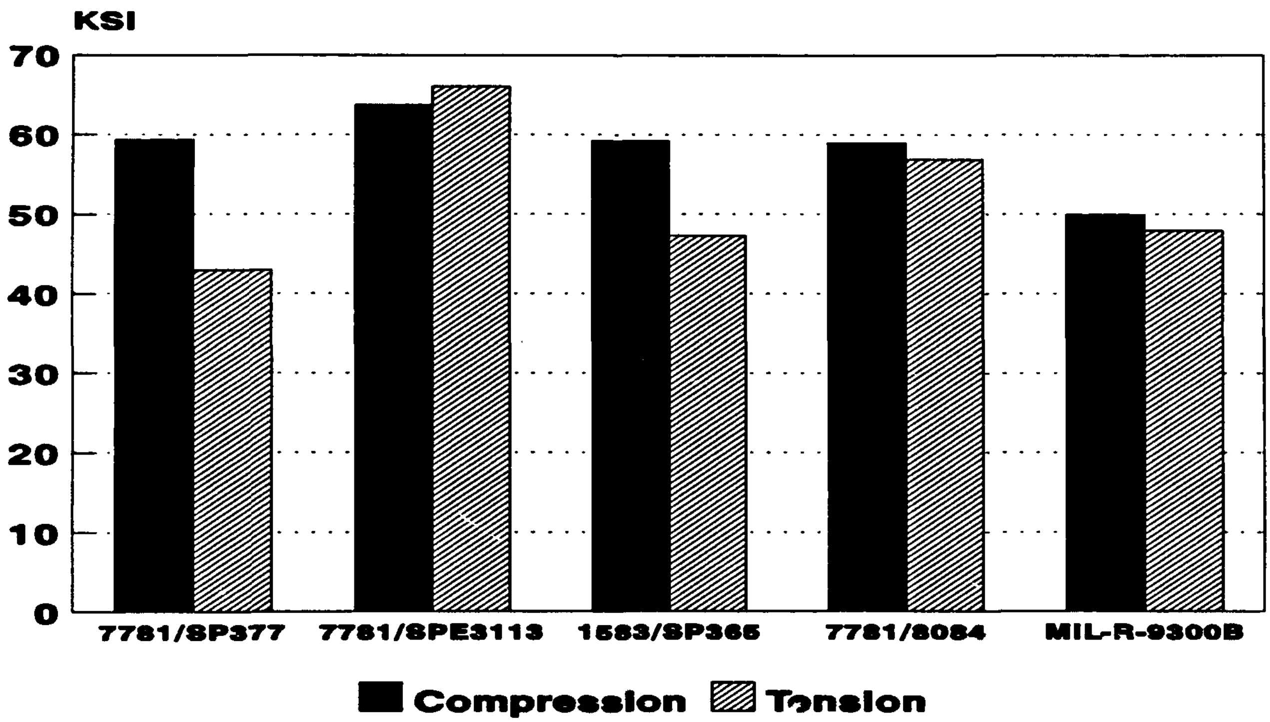


Fig. 15. A comparison of tensile strength with compressive strength of woven yarn reinforced laminates.

A comparison of tensile strength with compressive strength of woven roving laminates is shown in Figure 14, and the same strength comparison of woven yarn composites is shown in Figure 15. It is clear that the tensile strength usually exceeds the compressive. The first three materials in Figure 15 were taken on autoclave-consolidated prepregs at the Carderock Division, NSWC, and the fourth is the material evaluated in this study. Inspection of the textile fabric data show tensile strength values lower than compressive, which can be taken as evidence for the rough handling of the glass in woven yarn. It is interesting to note, as shown in Figure 15, that the compressive strength exceeds the tensile strength in MIL-R-9300B, the specification for textile fabric reinforced epoxies.

Inspection of failed flexural coupons supports the measured values of tensile and compressive strength. For woven roving laminates, and composites in general, flexural deformation results in failure on the compressive surface of the sample since these materials are weaker in compression than tension. In contrast, woven yarn laminates fail in tension when deformed in flexure due to the relative weakness just described. Furthermore, flexural failures are sometimes observed on both surfaces of the specimen, which almost invariably occurs when a material has approximately equal tensile and compressive strengths.

Fiber/Matrix Adhesion

The first laminate made with 7781 reinforcement had poor properties. It was decided that the fabric used probably had an epoxy compatible finish, and that inadequate fiber/matrix adhesion resulted in the poor properties of this material. Since the finish was not known, it is referred to as 7781(U) in this paper. Seemann Composites subsequently procured 7781 from Hexcel finished with F72, a vinyl ester compatible coupling agent. The strong effect of fiber/matrix adhesion can be seen in Figures 16 and 17, which compare strength and impact resistance, respectively, for 7781(U)

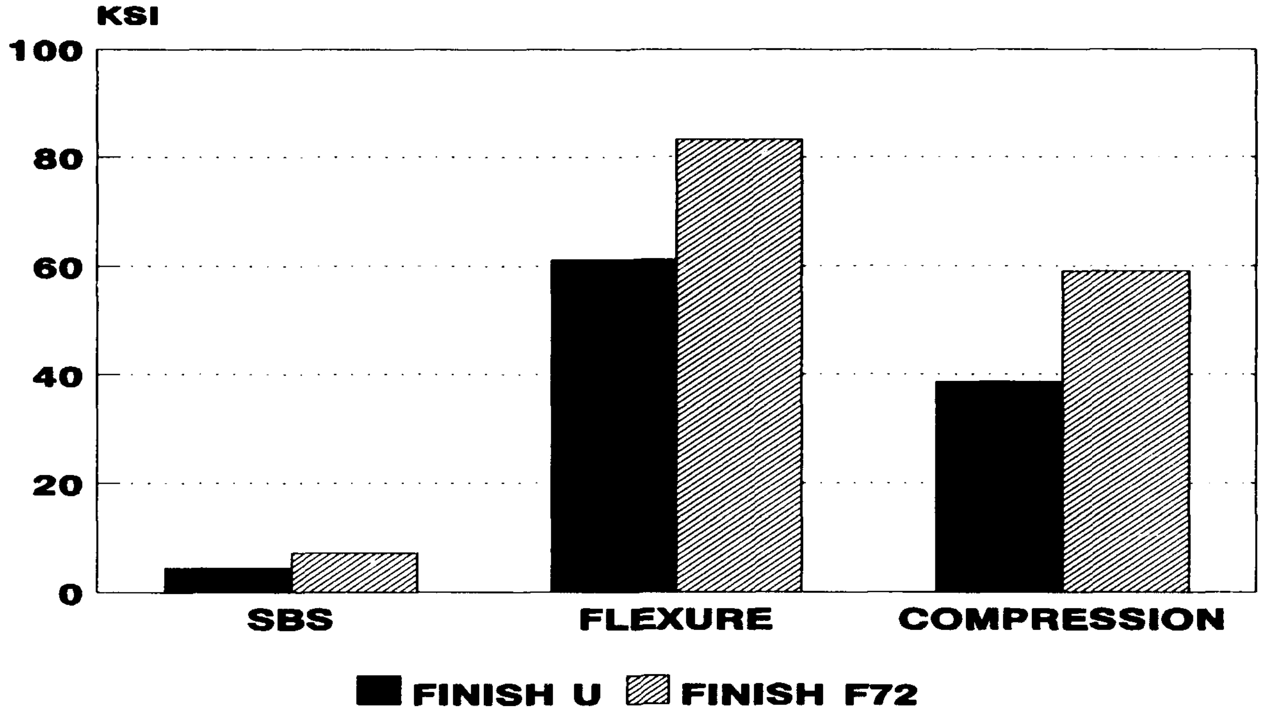
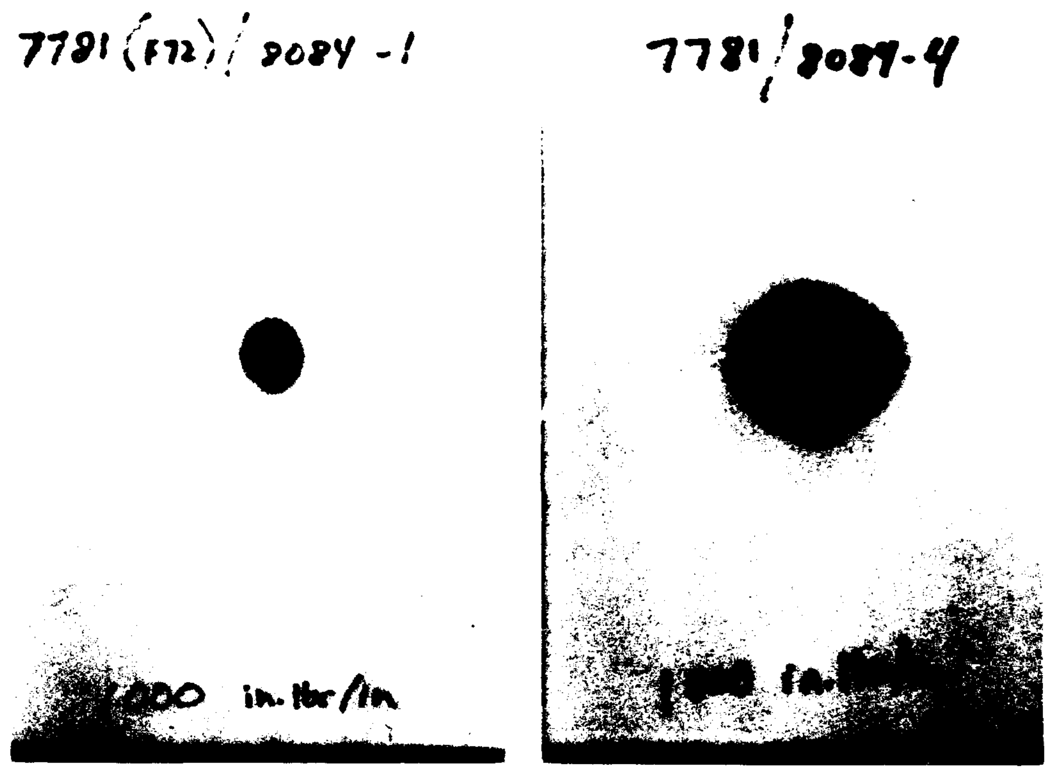


Fig. 16. The strength of 7781/8084 was a strong function of the finish applied to the fabric.

and 7781(F72). Glass reinforced composites will have low strength (except tensile, which does not depend on fiber/matrix adhesion) and resistance to impact damage if an inappropriate size or finish is applied to the glass.

Summary

The glass fabric survey reported herein indicates that for most Naval applications, the use of textile fabrics is not recommended unless their superior drape is required. Equivalent mechanical properties can be achieved at half the cost by a woven roving of comparable weight. Further cost reduction is realized with heavier fabrics with only a modest decrease in mechanical performance.



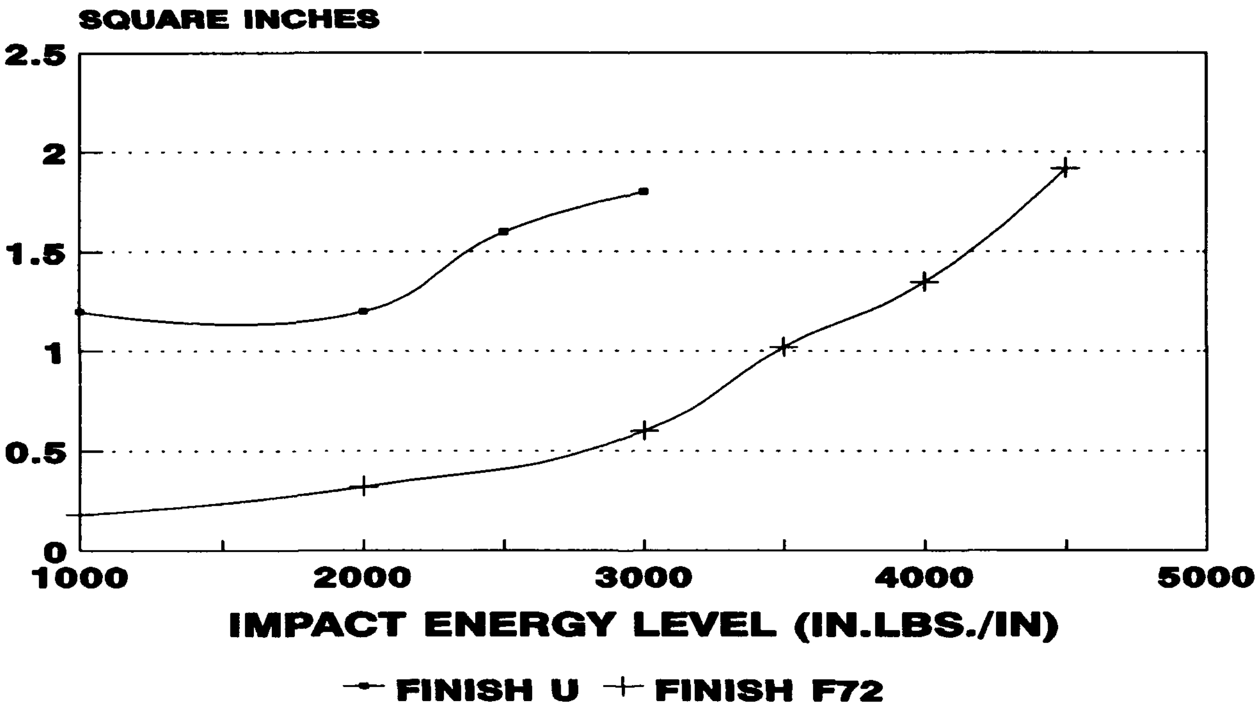


Fig. 17. The impact damage area of 7781 was a strong function of the fabric finish, as shown in the graph above. The data at 1000 in.lbs/in was measured from the panels pictured.

EFFECT OF FIBER

The effect of fiber type is shown in Figures 18-22. There are clearly large differences in the properties of composites reinforced with the various available fibers. Taking strength, impact resistance, and cost together, an overall superiority of glass is evident.

Strength

The compression strength data, Figure 18, shows comparable values for carbon/epoxy and glass/vinyl ester, but low strength for carbon/vinyl ester. We have attributed the poor performance of carbon/vinyl ester to interfacial adhesion, as discussed below.

The flexural strength of carbon/epoxy was significantly higher than that for glass/vinyl ester, for reasons which are not clear. (As has been said, flexural deformation results in a compressive failure, and the compression strength of carbon/epoxy and glass/vinyl ester were essentially the same, as shown in Figure 18.). The unusually high flexural strength of the carbon/epoxy materials may have been caused by the high uniaxial fiber content of the 5HS warp face.

The very low compression and flexural strength of the laminates reinforced with polymeric fibers was expected, as they have often been reported[9]. These materials perform well only in tension.

Impact Resistance

The composite panels with the best resistance to low velocity impact damage had glass reinforcement. Glass outperformed carbon, Spectra, Kevlar, and the hybrids.

The impact resistance of the carbon-reinforced materials was interesting. The carbon/vinyl ester panels, with poor fiber/matrix adhesion, sustained large delaminations due to impact. The spreading of the damage by delamination allowed these materials to resist penetration until 4000

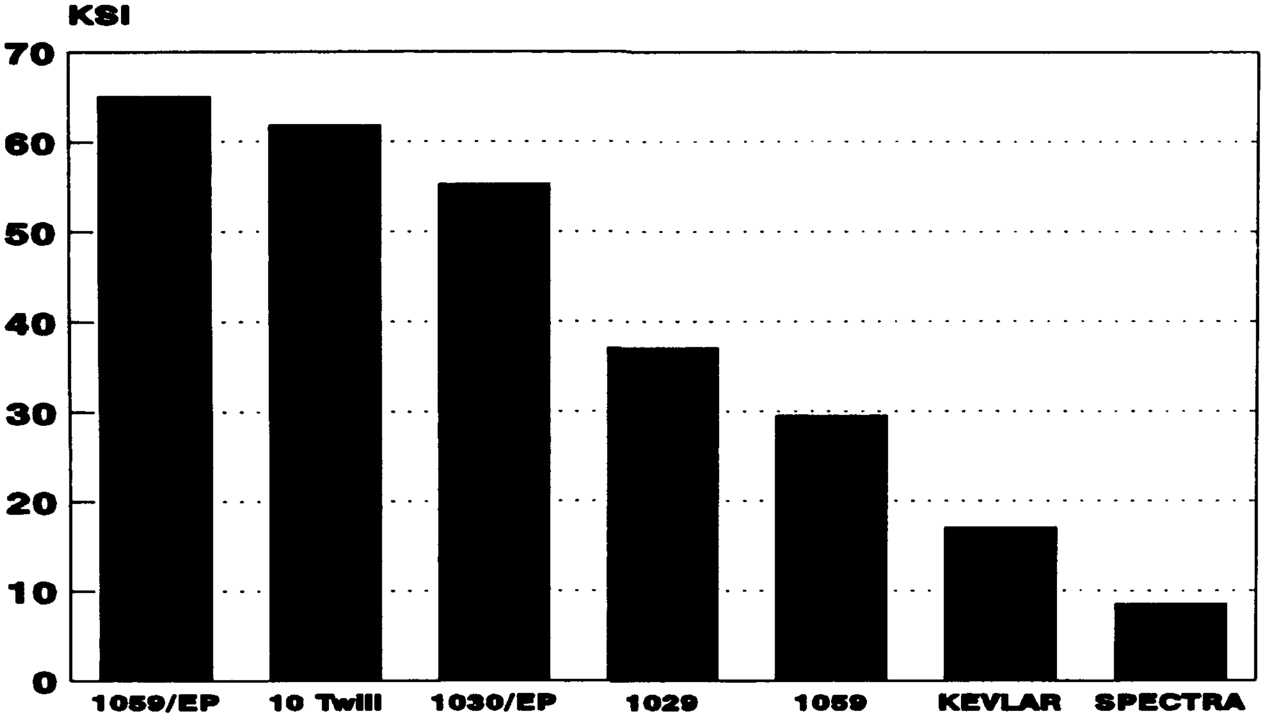


Fig. 18. The effect of fiber on compression strength. The resin was Derakane 8084 vinyl ester, except those materials indicated with EP, which had Epon 9405 epoxy.

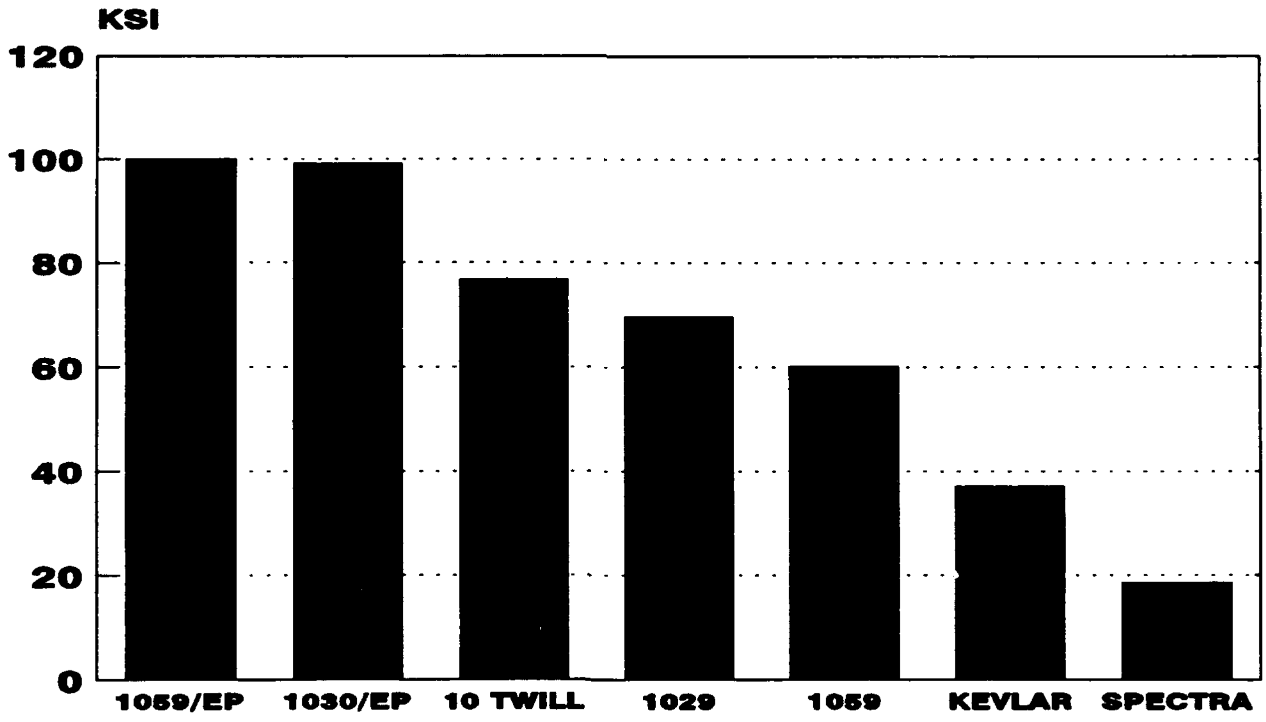


Fig. 19. The effect of fiber on flexural strength. The resin was Derakane 8084 vinyl ester, except those materials indicated with EP, which had Epon 9405 epoxy.

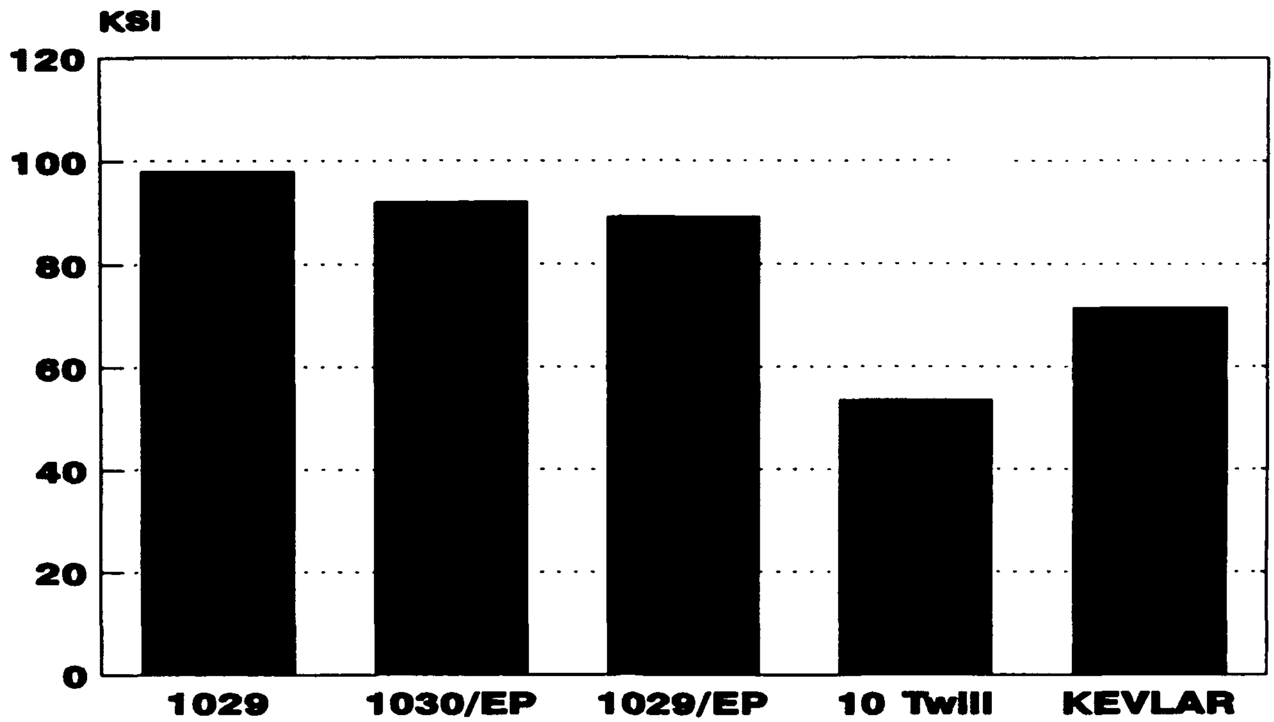


Fig. 20. The effect of fiber on tensile strength. The resin was Derakane 8084 vinyl ester, except those materials indicated with EP, which had Epon 9405 epoxy.

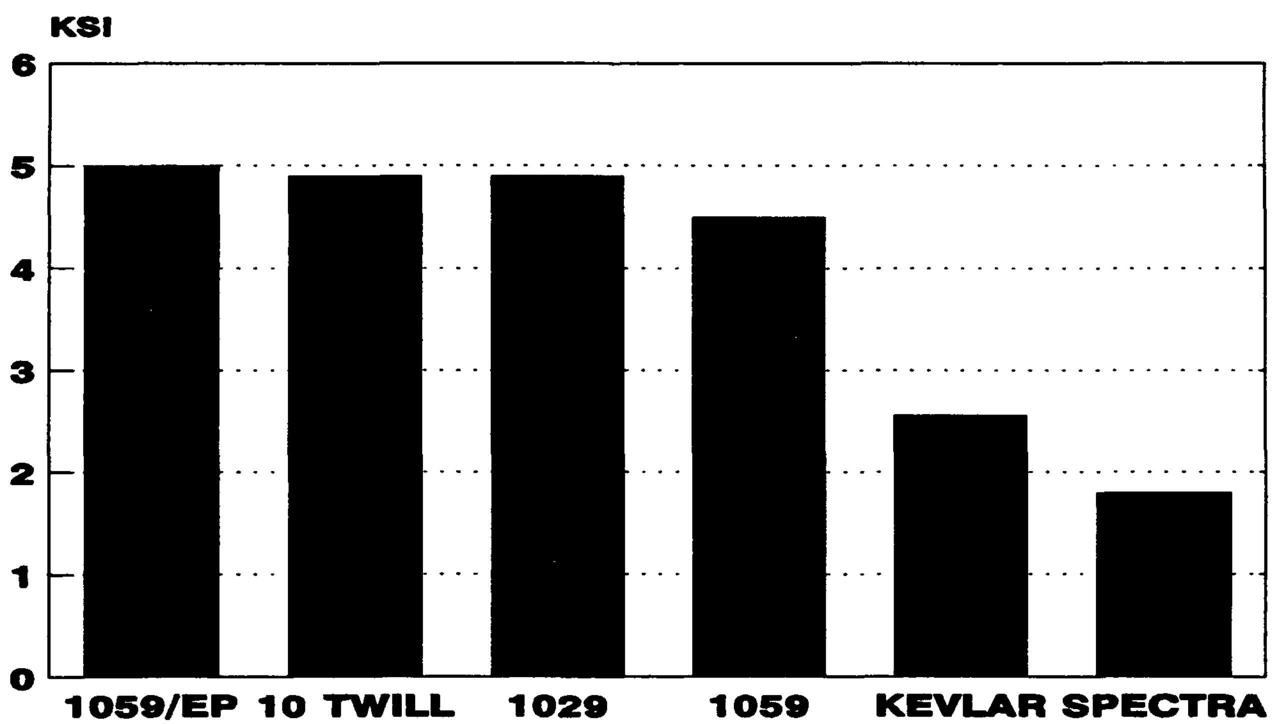


Fig. 21. The effect of fiber on SBS strength. The resin was Derakane 8084 vinyl ester, except the material indicated with EP, which had Epon 9405 epoxy.

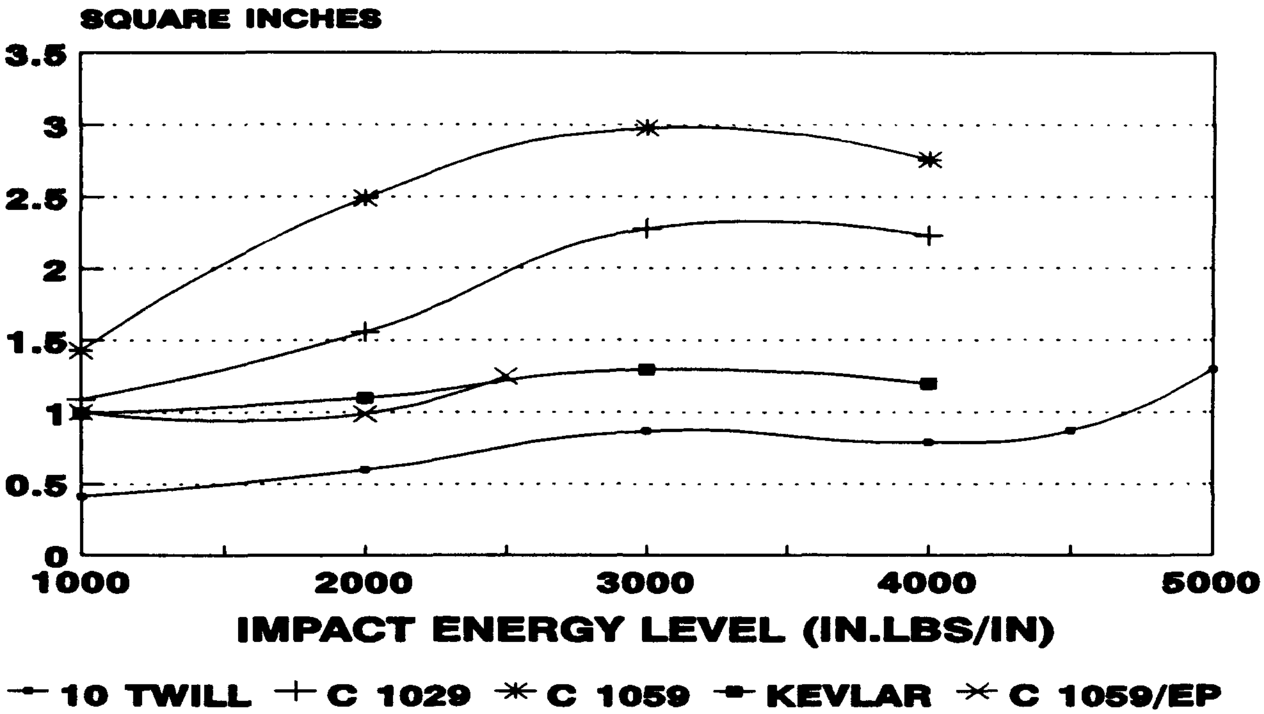


Fig. 22. The effect of fiber on impact damage area. The resin was Derakane 8084 vinyl ester, except the material indicated with EP, which had Epon 9405 epoxy.

in.lbs/in. The carbon/epoxy laminates did not delaminate substantially, but this resistance to the spread of damage caused penetration at very low impact levels.

The two polymer fiber reinforced materials did not perform as well as glass laminates. As mentioned, the impact levels were normalized for panel thickness. If the tests had been run on a weight basis, Kevlar and Spectra would have outperformed glass. Both the Kevlar and Spectra panels penetrated at 4000 in.lbs/in.

The Spectra/vinyl ester panels tested in this program did not develop well defined damage zones at the impact site, as in the case of glass, carbon, and Kevlar. The impacts resulted in large plastic deformation of these laminates, so it was not possible to accurately determine damage areas.

Fiber/Matrix Adhesion

The three carbon fiber reinforced vinyl esters evaluated had low compression strength and relatively low flexural strength compared to carbon/epoxy and glass/vinyl ester. All three fabrics were composed of carbon tow which had been sized with epoxy-compatible coatings. Vinyl ester chemistry cannot react with epoxy chemistry, and it is evident that the poor performance of carbon/vinyl ester was caused by inadequate fiber/matrix adhesion.

SEM micrographs of a carbon/epoxy (1059/9405) failure is compared with carbon/vinyl ester (1059/8084) in Figure 23, where a difference in level of adhesion is clear. Also presented in Figure 23 is the effect of water immersion on the flexural strength of these two materials. The flexural strength of carbon/vinyl ester is further degraded by water, an indication of an adhesion problem.

The performance of carbon/vinyl ester in our study suggests that the development of vinyl ester compatible sizes is necessary before these material systems achieve their full potential. It must be noted, however, that the carbon/vinyl ester properties reported in Reference 6 did not indicate an adhesion problem. The fiber tested in that reference was AS4, but the size was not mentioned.

EFFECT OF HYBRID REINFORCEMENT

Glass fiber is an excellent overall performer for strength, impact resistance, and cost. However, for applications where weight is critical, glass becomes less desirable. This is shown in Table 6, where properties on a volume basis are compared with properties on a weight basis, the latter obtained by dividing by the composite density.

Carbon appears particularly efficient for strength/weight and stiffness/weight designs, but its low resistance to impact damage (Figure 22), high cost, and concerns with corrosion[10,11] make the general use of carbon for marine applications unlikely.

Kevlar and Spectra are competitive with glass and carbon on a weight basis in tension (the

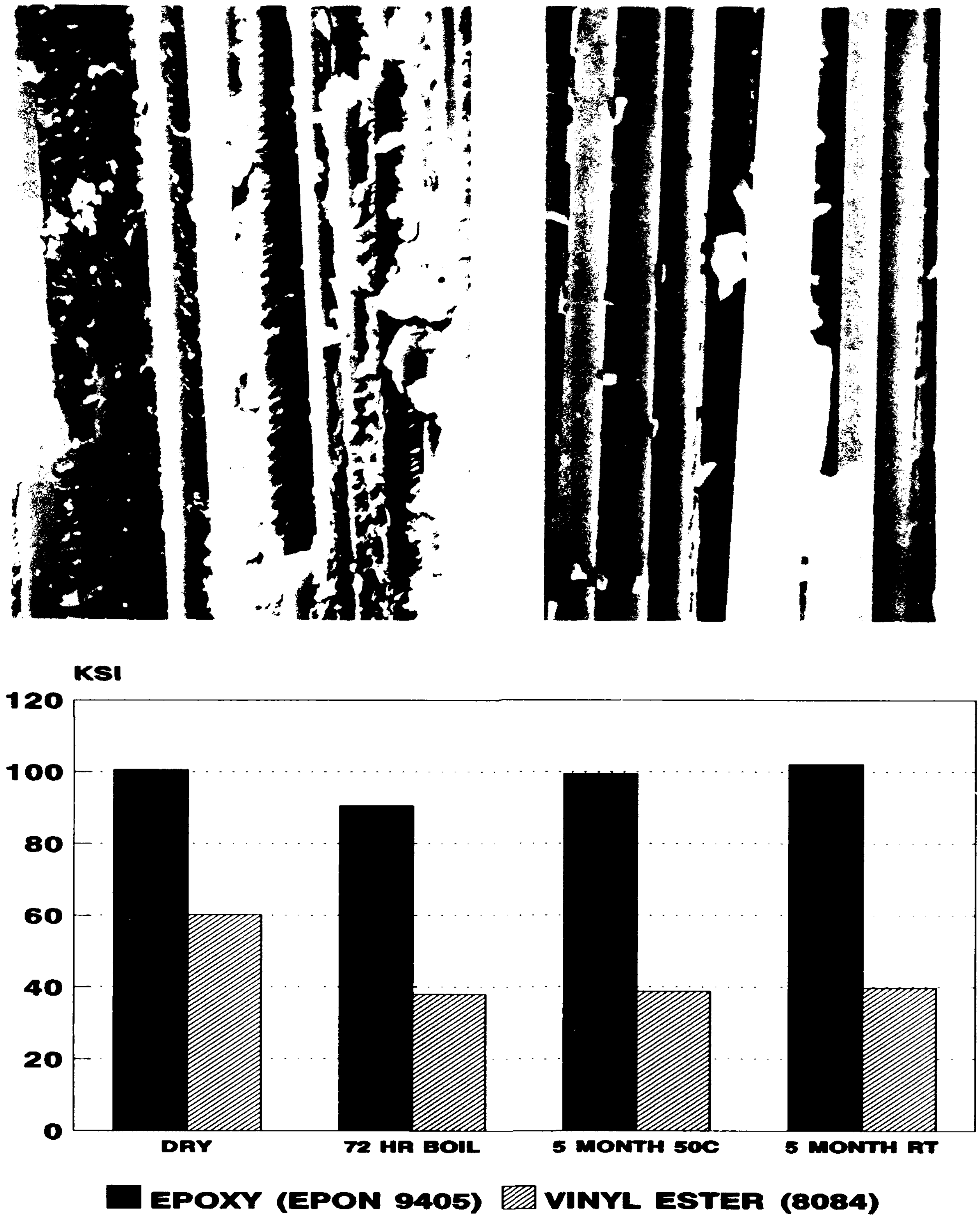


Fig. 23. Flexural strength degradation after immersion and the appearance of dry failure surfaces (right) indicate fiber/matrix adhesion problems in the carbon vinyl ester. Carbon/epoxy (left) appears well bonded.

Table 6. **A comparison of strength (σ, in ksi) and modulus (E, in msi) with σ/δ and E/δ.**

Fiber /8084	δ $\frac{lb}{in^3}$	Tensile		Compressive		Flexure		Modulus	
		σ	$\frac{\sigma}{\delta}$	σ	$\frac{\sigma}{\delta}$	σ	$\frac{\sigma}{\delta}$	E	$\frac{E}{\delta}$
E-glass	0.068	53.6	788	61.7	907	76.7	1128	3.4	50
Carbon	0.054	98.0	1815	37.0	685	69.7	1291	8.3	154
Kevlar	0.049	69.5	1418	15.8	322	35.5	724	4.3	88
Spectra	0.039	-	-	8.5	218	18.5	474	2.1	54

Spectra samples sheared to failure in the grips during testing), but are less load bearing in other states of stress.

Given that a single reinforcement does not possess all the properties required to optimize strength/weight, impact resistance, cost, and environmental effects concerns, hybrid laminates composed of E-glass with an advanced fiber were evaluated. As mentioned, the test specimens were fabricated with each of the hybridizing materials forming a "core" sandwiched between two E-glass skins. Data taken on the hybrid laminates is presented in Figures 24-27.

Strength

Compression strength values of the hybrids were low compared to glass alone. In contrast, the flexural and tensile strength of the hybrids were superior or comparable to that of glass. Hybrid laminates, in the "sandwich" configuration as tested here, can support more load in bending than homogeneous reinforcement if the inner plys have a higher Young's modulus than the outer plys. This was the case in all six hybrids evaluated.

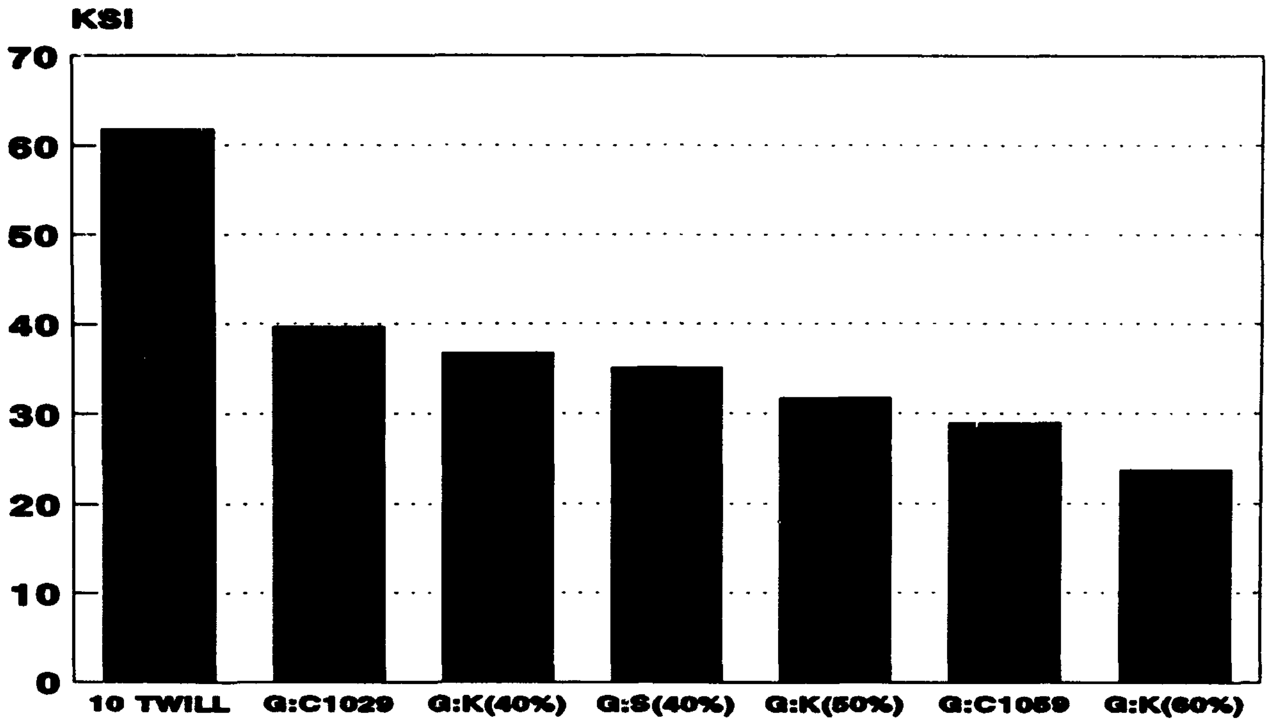


Fig. 24. The effect of hybrid reinforcement on compression strength. Derakane 8084 was used throughout. The properties of an all-glass panel are included for comparison.

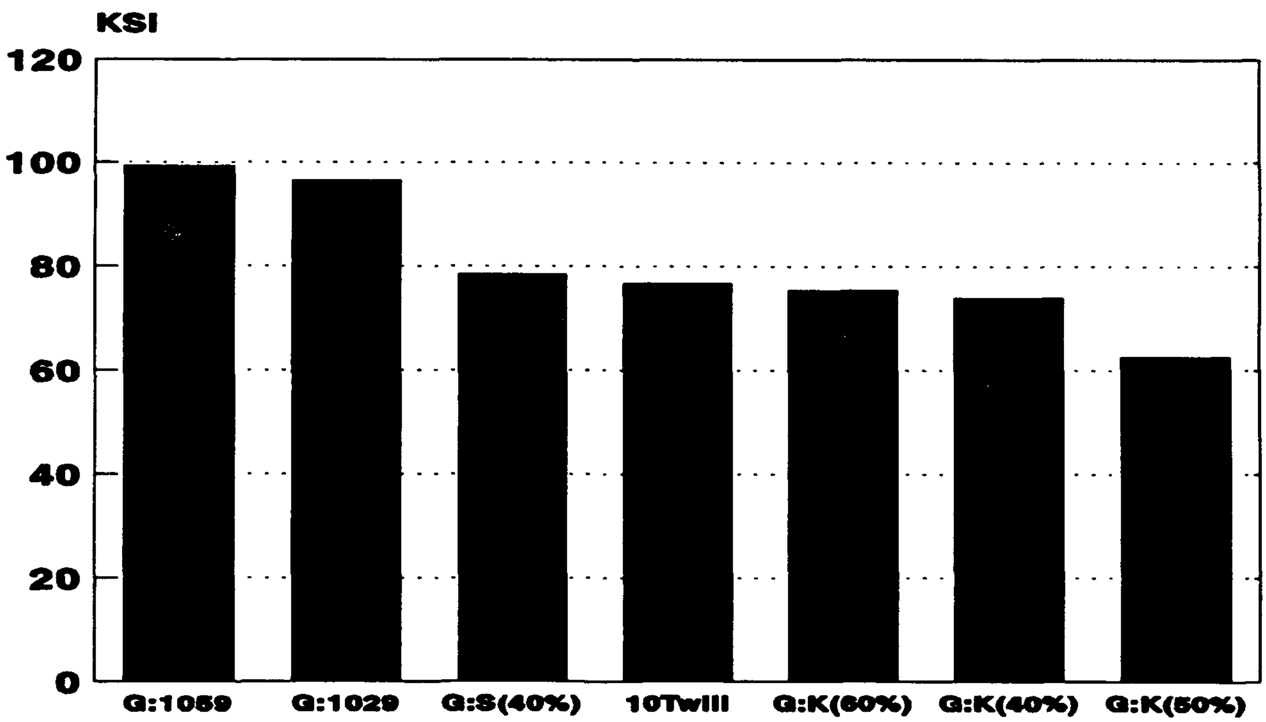


Fig. 25. The effect of hybrid reinforcement on flexural strength. Derakane 8084 was used throughout. The properties of an all-glass panel are included for comparison.

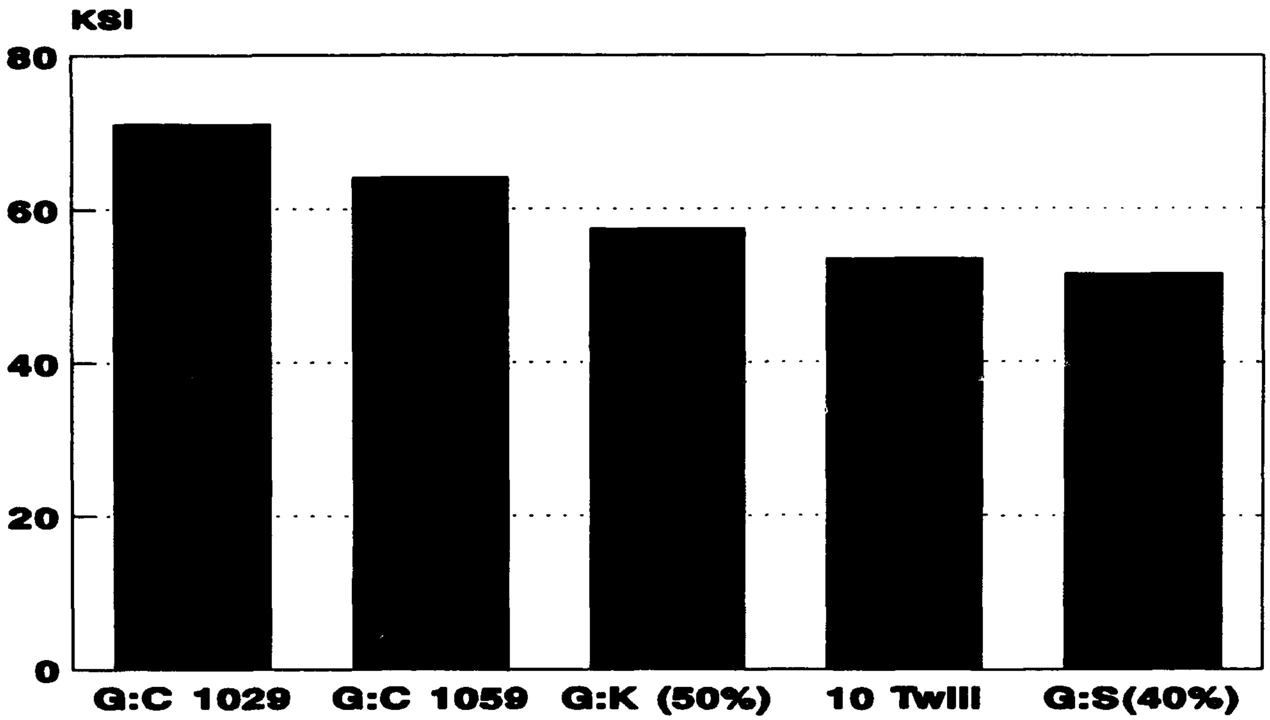


Fig. 26. The effect of hybrid reinforcement on tensile strength. Derakane 8084 was used throughout. The properties of an all-glass panel are included for comparison.

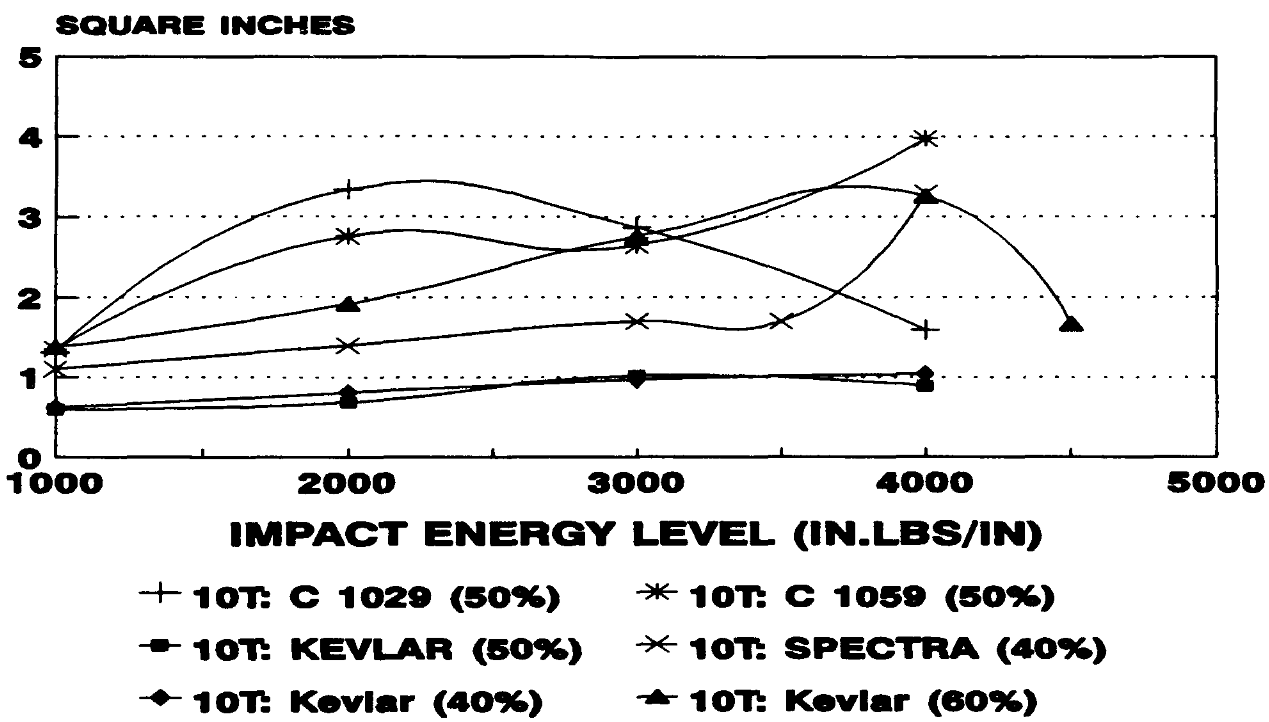


Fig. 27. The effect of hybrid reinforcement on impact damage area. Derakane 8084 was used throughout. Only the hybrids of Kevlar (at 40% and 50%) retained the excellent impact resistance of glass.

Impact Resistance

The impact resistance, shown in Figure 27, was poor in general, due to the formation of large delaminations at the interface between hybrid layers. However, certain glass:Kevlar hybrids were found to retain exceptional resistance to impact damage. Inspection of Figure 25 shows that large delaminations did not occur in the Kevlar hybrids having 40% and 50% Kevlar by volume. However, a laminate composed of 60% Kevlar did delaminate upon impact. It must be noted that, as described in Table 4, the Kevlar hybrid composed of 60% Kevlar (40% glass) had style 285 fabric, whereas the other two hybrids had style 900. In addition, the panel thickness of the 60% Kevlar hybrid was nominally 0.19" whereas the 40% Kevlar panel was about 0.12" thick, and the 50% Kevlar was 0.13" thick. It was not determined whether the impact resistance of glass:Kevlar hybrids is controlled by Kevlar volume fraction, fabric style, thickness of the Kevlar plys, or overall panel thickness.

SUMMARY AND CONCLUSIONS

EFFECT OF RESIN

Compression and flexural strength of glass fabric reinforced composites increased with resin modulus if the resin failure strain was above some critical value. The impact damage resistance of the glass laminates was independent of resin failure strain if the resin failure strain was above some critical value. Vinyl esters and epoxies of comparable stiffness have comparable properties. The polyester tested was inferior to epoxies and vinyl esters because of its low failure strain.

EFFECT OF GLASS FABRIC STYLE

Woven rovings were the overall best performers taking cost and properties into consideration. There were no significant advantages to the higher cost versions of E-glass, namely, woven yarn, stitched biaxial, or spun roving. Glass/resin coupling agent was critical to the strength and impact damage resistance.

EFFECT OF FIBER

Glass fiber was the overall best performer for strength and impact resistance. Carbon was poor in impact, Kevlar and Spectra had low strength. The carbon/vinyl ester materials tested had poor fiber/matrix adhesion.

EFFECT OF HYBRID

The hybrid concept evaluated, with glass outer plys and carbon, Kevlar, or Spectra inner plys, was effective only with Kevlar. Carbon and Spectra hybrids sustained large delaminations upon impact.

APPENDIX A - STRENGTH AND MODULUS DATA

Table A.1. The data taken in this study. Strengths are in ksi, Young's moduli in msi.

Material	Compression Strength	Flexure Strength	Tension Strength	Tension Modulus	SBS
Woven Roving/510A	52.0	79.5	57.1	-	5.8
Woven Roving/8084	47.8	71.9	51.6	3.5	5.3
Woven Roving/123	43.6	70.6	-	-	5.1
Woven Roving/8510	32.8	55.0	51.5	3.9	5.1
Woven Roving/8520	32.2	58.2	48.7	3.9	4.2
Woven Roving/8472	30.8	48.7	44.7	3.6	3.5
10 Twill/8084	61.7	76.7	53.6	3.4	4.9
7781/8084	58.1	83.6	56.9	3.4	7.1
Chomarat/8084	55.0	69.3	40.2	2.9	6.2
24 Twill/8084	52.9	79.1	51.3	3.1	5.7
Biaxial/8084	41.5	59.7	50.1	3.2	4.7
DF1400(Fill)/8084	39.3	61.3	47.2	3.9	5.6
DF1400(Warp)/8084	34.7	46.2	35.0	3.4	4.7
1059(XASg)/9405	64.5	100.1	89.2	8.3	5.0
1030/9405	57.2	99.2	92.0	8.5	5.0
1029(AS4W)/8084	37.0	69.7	98.0	8.3	4.9
1029(UC309)/8084	42.1	68.2	-	-	-
1059(XASg)/8084	29.5	60.2	-	7.9	4.4
Kevlar(900)/8084	15.8	35.5	69.5	4.3	2.4
Spectra(985)/8084	8.5	18.5	-	2.1	1.8
G:C1029/8084	39.7	96.5	71.1	6.4	4.4
G:C1059/8084	29.0	99.3	64.2	6.1	4.3
G:K900(40%)/8084	36.7	73.9	-	-	-
G:K900(50%)/8084	31.8	62.6	57.5	3.7	-
G:K285(60%)/8084	23.8	75.4	-	-	3.7
G:S985(40%)/8084	35.1	78.5	51.5	3.1	3.1

Table A.2. In-plane shear strength (S) and modulus (Gxy).

Material	Shear Strength	Shear Modulus
Woven Roving/8084	9.5	0.62
10 Twill/8084	9.4	0.58
G:K900(50%)/8084	8.1	0.44

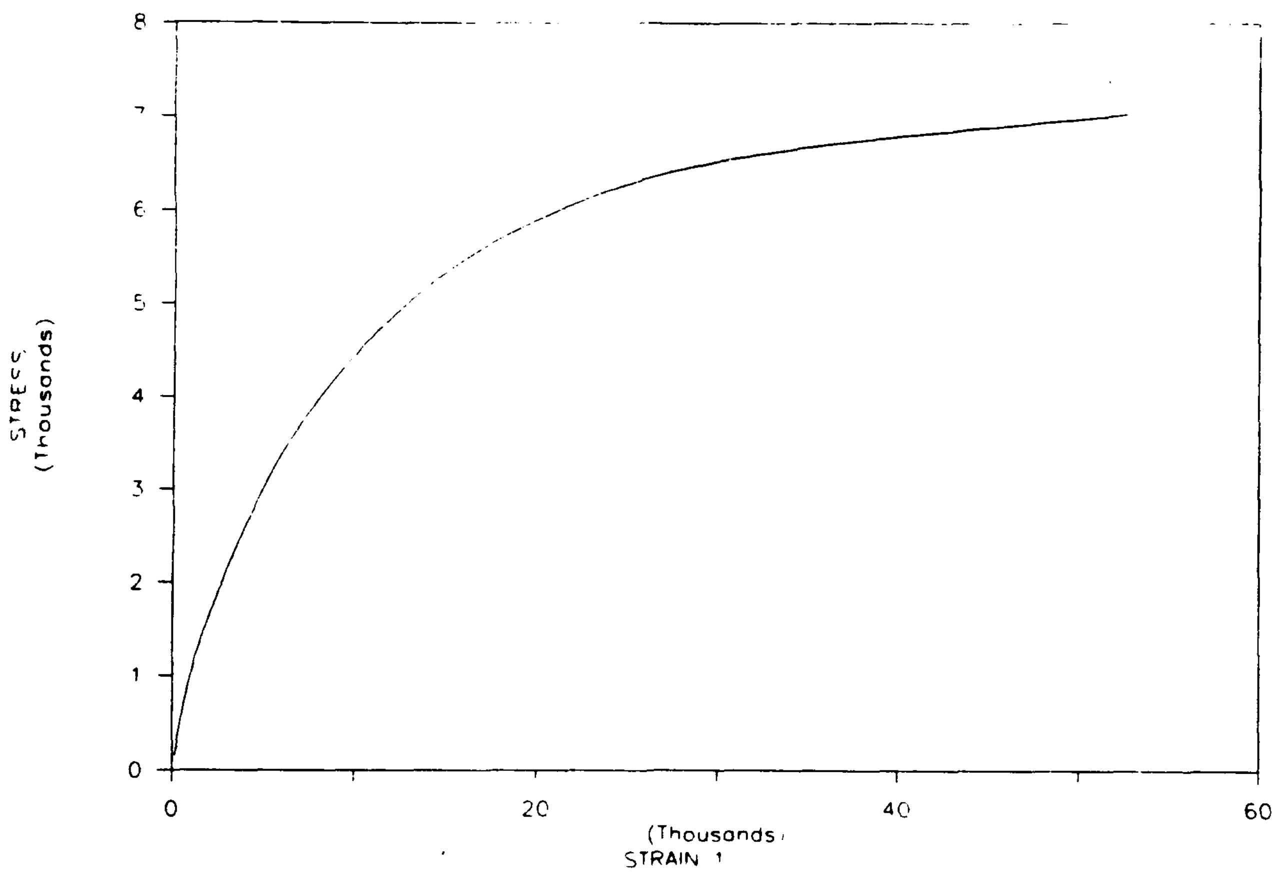


Fig. A.1. Shear stress/strain curve for WR/8084. The modulus in Table A.2 was determined by the initial slope.

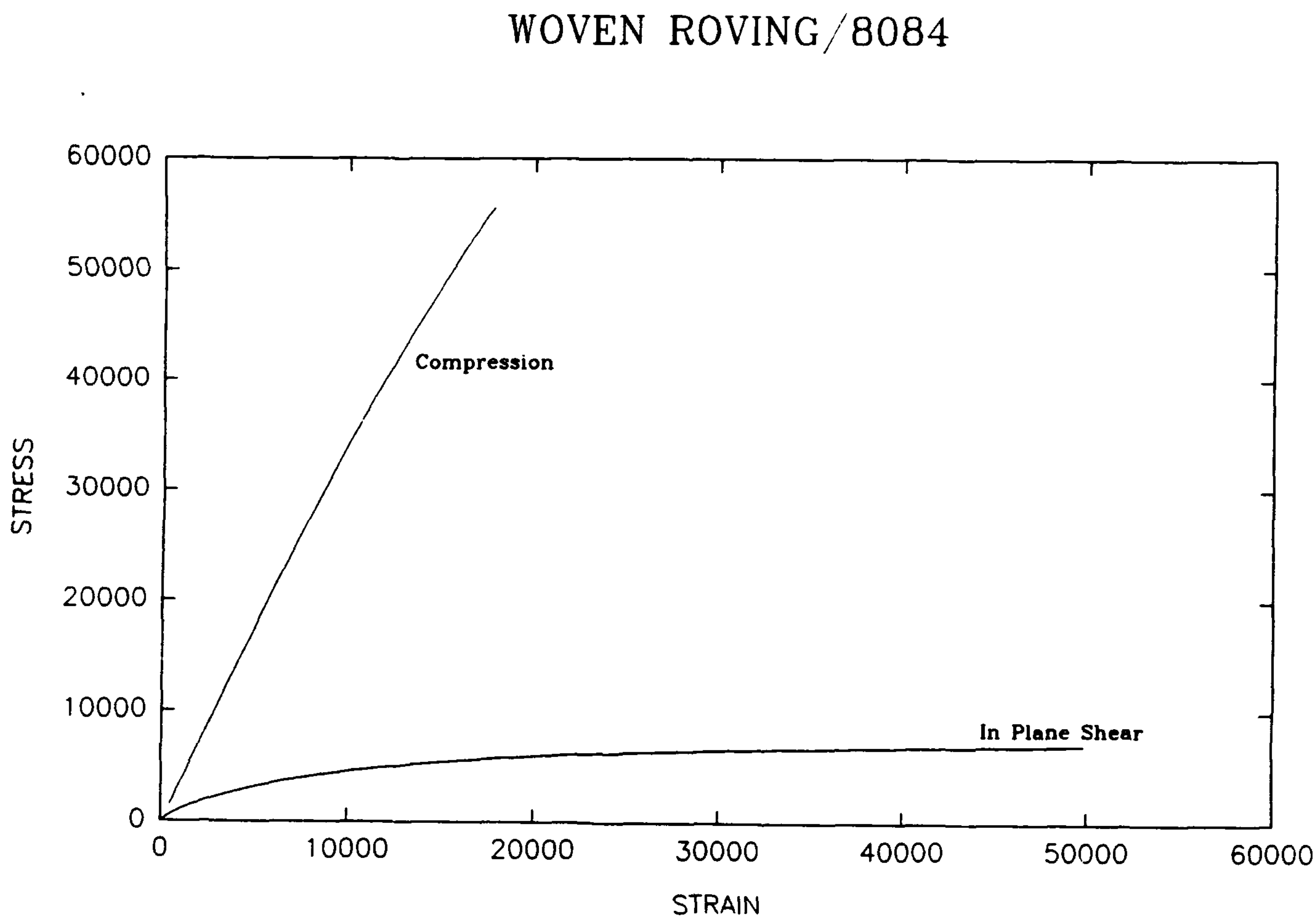


Fig. A.2. **Woven Roving/8084 stress/strain curves for in-plane compression and shear.**

Table A.3. Raw data for ASTM D 695 compression test.

13-15oz Stitched Biax/8084

Sample	thickness	width	Load	sig_c
1	0.175	0.507	3536	39853.5
2	0.166	0.51	3480	41105.6
3	0.173	0.51	3753	42536.6
4	0.175	0.513	3620	40323.0
5	0.174	0.506	3826	43455.5
Avg.	0.173	0.509	3643	41454.8
Std. dev.	0.004	0.003	145	1511.6
Coef of var.	2.2%	0.5%	4.0%	3.6%

24oz WR/8510

Sample	thickness	width	Load	sig_c
1	0.152	0.465	2211	31281.8
2	0.151	0.467	2400	34034.3
3	0.151	0.468	2564	36282.3
4	0.152	0.468	2038	28649.3
5	0.153	0.469	2405	33515.9
Avg.	0.152	0.467	2324	32752.8
Std. dev.	0.001	0.002	203	2901.9
Coef of var.	0.6%	0.3%	8.7%	8.9%

8.9oz 7781/8084 (8H satin)

Sample	thickness	width	Load	sig_c
1	0.151	0.5	4756	62993.4
2	0.151	0.504	3542	46541.6
3	0.151	0.508	4351	56721.6
4	0.152	0.505	4834	62975.5
5	0.15	0.498	4938	66104.4
Avg.	0.151	0.503	4484	59067.3
Std. dev.	0.001	0.004	572	7787.9
Coef of var.	0.5%	0.8%	12.8%	13.2%

24oz WR/8520

Sample	thickness	width	Load	sig_c
1	0.145	0.509	2319	31420.6
2	0.146	0.508	2640	35594.9
3	0.148	0.509	2588	34354.6
4	0.147	0.507	2438	32712.1
5	0.146	0.51	1991	26739.2
Avg.	0.146	0.509	2395	32164.3
Std. dev.	0.001	0.001	259	3422.4
Coef of var.	0.8%	0.2%	10.8%	10.6%

24oz twill/8084

Sample	thickness	width	Load	sig_c
1	0.16	0.507	4239	52255.9
2	0.16	0.507	4386	54068.0
3	0.156	0.51	4632	58220.2
4	0.158	0.509	4104	51030.8
5	0.159	0.507	3962	49148.4
Avg.	0.159	0.508	4265	52944.7
Std. dev.	0.002	0.001	259	3451.2
Coef of var.	1.1%	0.3%	6.1%	6.5%

24 oz WR/Tactix 123

Sample	thickness	width	Load	sig_c
1	0.156	0.512	3515	44007.9
2	0.15	0.511	3640	47488.6
3	0.156	0.514	3578	44622.4
4	0.147	0.512	3323	44151.3
5	0.162	0.509	3107	37679.8
Avg.	0.154	0.512	3433	43590.0
Std. dev.	0.006	0.002	217	3594.6
Coef of var.	3.8%	0.4%	6.3%	8.2%

24 oz WR/8084

Sample	thickness	width	Load	sig_c
1	0.146	0.47	3388	49373.4
2	0.145	0.466	2909	43051.7
3	0.145	0.465	3433	50915.8
4	0.146	0.465	3361	49506.6
5	0.145	0.465	3119	46258.8
Avg.	0.145	0.466	3242	47821.2
Std. dev.	0.001	0.002	222	3162.9
Coef of var.	0.4%	0.5%	6.9%	6.6%

9.6oz twill/8084

Sample	thickness	width	Load	sig_c
1	0.15	0.475	4304	60407.0
2	0.155	0.485	4524	60179.6
3	0.153	0.486	4820	64821.5
4	0.153	0.484	4439	59944.4
5	0.151	0.481	4592	63223.7
Avg.	0.152	0.482	4536	61715.2
Std. dev.	0.002	0.004	192	2186.9
Coef of var.	1.3%	0.9%	4.2%	3.5%

G:K900(50%)/8084

Sample	thickness	width	Load	sig_c
1	0.113	0.519	1727	29447.4
2	0.112	0.511	1985	34683.4
3	0.114	0.522	2108	35423.8
4	0.116	0.515	1821	30482.1
5	0.113	0.507	1646	28730.5
Avg.	0.114	0.515	1857	31753.4
Std. dev.	0.002	0.006	188	3087.4
Coef of var.	1.3%	1.2%	10.1%	9.7%

800gm (28oz) Chomarat/8084

Sample	thickness	width	Load	sig_c
1	0.192	0.51	5727	58486.5
2	0.191	0.508	5563	57334.0
3	0.195	0.508	4940	49868.8
4	0.195	0.507	5780	58463.6
5	0.195	0.508	5022	50696.5
Avg.	0.194	0.508	5406	54969.9
Std. dev.	0.002	0.001	398	4314.1
Coef of var.	1.0%	0.2%	7.4%	7.8%

Table A.3. (Continued)

10.9oz C1029(AS4W)/8084

Sample	thickness	width	Load	sig_c
1	0.156	0.498	2513	32347.3
2	0.156	0.505	2583	32787.5
3	0.157	0.49	2926	38034.6
4	0.157	0.485	3144	41289.6
5	0.158	0.505	3232	40506.3
Avg.	0.157	0.497	2880	36993.1
Std. dev.	0.001	0.009	324	4217.8
Coef of var.	0.5%	1.8%	11.2%	11.4%

9.6 Twill/C1029/8084

Sample	thickness	width	Load	sig_c
1	0.172	0.493	2980	35143.2
2	0.173	0.483	3009	36010.5
3	0.173	0.494	3420	40017.8
4	0.172	0.495	3704	43504.8
5	0.17	0.485	3611	43796.2
Avg.	0.172	0.490	3345	39694.5
Std. dev.	0.001	0.006	336	4053.8
Coef of var.	0.7%	1.1%	10.0%	10.2%

G:K900(40%)/8084

Sample	thickness	width	Load	sig_c
1	0.131	0.512	2519	37556.7
2	0.13	0.511	2283	34367.0
3	0.135	0.52	2663	37934.5
4	0.134	0.511	2671	39007.5
5	0.132	0.51	2326	34551.4
Avg.	0.132	0.513	2492	36683.4
Std. dev.	0.002	0.004	183	2100.0
Coef of var.	1.6%	0.8%	7.3%	5.7%

9.6oz Twill/C1059/8084

Sample	thickness	width	Load	sig_c
1	0.16	0.475	2256	29684.2
2	0.161	0.475	2333	30506.7
3	0.158	0.476	2075	27590.1
4	0.16	0.48	2066	26901.0
5	0.16	0.479	2327	30362.7
Avg.	0.160	0.477	2211	29009.0
Std. dev.	0.001	0.002	132	1657.4
Coef of var.	0.7%	0.5%	6.0%	5.7%

9.6oz Twill/SPECTRA(40%)/8084

Sample	thickness	width	Load	sig_c
1	0.134	0.472	2363	37360.9
2	0.129	0.472	2035	33422.0
3	0.129	0.47	2178	35922.8
4	0.132	0.478	2145	33995.8
5	0.131	0.476	2175	34880.4
Avg.	0.131	0.474	2179	35116.4
Std. dev.	0.002	0.003	118	1570.8
Coef of var.	1.6%	0.7%	5.4%	4.5%

9.6oz Twill/KEVLAR(60%)/8084

Sample	thickness	width	Load	sig_c
1	0.191	0.488	2087	22390.8
2	0.188	0.492	2430	26271.4
3	0.192	0.48	2186	23719.6
4	0.187	0.484	2149	23743.8
5	0.188	0.486	2068	22633.7
Avg.	0.189	0.486	2184	23751.9
Std. dev.	0.002	0.004	145	1537.2
Coef of var.	1.1%	0.9%	6.7%	6.5%

Kevlar 900/8084

Sample	thickness	width	Load	sig_c
1	0.168	0.502	1404	16647.7
2	0.167	0.507	1353	15979.9
3	0.162	0.513	1331	16015.7
4	0.167	0.504	1242	14756.2
5	0	0	0	0.0
Avg.	0.166	0.507	1333	15849.9
Std. dev.	0.003	0.005	68	791.0
Coef of var.	1.6%	0.9%	5.1%	5.0%

DF1400(warp)/8084

Sample	thickness	width	Load	sig_c
1	0.239	0.5	4260	35648.5
2	0.245	0.496	4124	33936.8
3	0.241	0.497	3967	33119.9
4	0.241	0.495	4148	34770.9
5	0.245	0.495	4359	35943.1
Avg.	0.242	0.497	4172	34683.9
Std. dev.	0.003	0.002	148	1175.6
Coef of var.	1.1%	0.4%	3.5%	3.4%

C1059(XASg)/8084

Sample	thickness	width	Load	sig_c
1	0.18	0.502	3150	34860.6
2	0.172	0.496	2451	28729.8
3	0.18	0.495	2562	28754.2
4	0.175	0.502	2610	29709.7
5	0.175	0.498	2217	25438.9
Avg.	0.176	0.499	2598	29498.6
Std. dev.	0.004	0.003	344	3406.7
Coef of var.	2.0%	0.7%	13.2%	11.5%

C1029(UC309)/8084

Sample	thickness	width	Load	sig_c
1	0.159	0.503	3309	41374.4
2	0.154	0.505	3194	41069.8
3	0.157	0.501	3409	43340.1
4	0.157	0.503	3432	43459.0
5	0.158	0.503	3294	41447.5
Avg.	0.157	0.503	3328	42138.2
Std. dev.	0.002	0.001	96	1160.9
Coef of var.	1.2%	0.3%	2.9%	2.8%

Table A.3. (Continued)

Spectra(985)/8084

Sample	thickness	width	Load	sig_c
1	0.116	0.489	474	8356.3
2	0.116	0.488	506	8938.7
3	0.116	0.484	476	8478.2
4	0.116	0.49	470	8268.8
5	-	-	-	-
Avg.	0.116	0.488	482	8510.5
Std. dev.	0.000	0.003	241	298.1
Coef of var.	0.0%	0.5%	50.1%	3.5%

DF1400(fill)/8084

Sample	thickness	width	Load	sig_c
1	0.264	0.503	5435	40928.7
2	0.255	0.501	5672	44397.5
3	0.25	0.503	4463	35491.1
4	0.262	0.503	4138	31399.4
5	0.26	0.504	5810	44337.6
Avg.	0.258	0.503	5104	39310.8
Std. dev.	0.006	0.001	754	5721.5
Coef of var.	2.2%	0.2%	14.8%	14.6%

24 oz WR/8472

Sample	thickness	width	Load	sig_c
1	0.153	0.503	2397	31146.5
2	0.151	0.508	2349	30622.6
3	0.143	0.507	2426	33461.6
4	0.151	0.505	2141	28076.8
5	-	-	-	-
Avg.	0.150	0.506	2328	30826.9
Std. dev.	0.004	0.002	129	2209.7
Coef of var.	3.0%	0.4%	5.5%	7.2%

C1059(XASg)/9405

Sample	thickness	width	Load	sig_c
1	0.125	0.507	4344	68544.4
2	0.127	0.506	4060	63178.9
3	0.123	0.508	4169	66721.1
4	0.125	0.506	3952	62482.2
5	0.127	0.504	3949	61695.4
Avg.	0.125	0.506	4095	64524.4
Std. dev.	0.002	0.001	166	2956.8
Coef of var.	1.3%	0.3%	4.1%	4.6%

24 oz WR/510A

Sample	thickness	width	Load	sig_c
1	0.148	0.508	-	0.0
2	0.152	0.512	4350	55895.4
3	0.145	0.506	3656	49829.6
4	0.15	0.513	4057	52722.5
5	0.149	0.509	3752	49471.9
Avg.	0.149	0.510	3954	51979.9
Std. dev.	0.003	0.003	315	2988.6
Coef of var.	2.0%	0.6%	8.0%	5.7%

C1030/9405

Sample	thickness	width	Load	sig_c
1	0.118	0.507	3080	51482.6
2	0.118	0.507	3310	55327.1
3	0.118	0.507	4435	74131.6
4	0.118	0.508	2902	48411.9
5	0.118	0.508	3385	56469.4
Avg.	0.118	0.507	3422	57164.5
Std. dev.	0.000	0.001	597	10007.9
Coef of var.	0.0%	0.1%	17.5%	17.5%

name

Sample	thickness	width	Load	sig_c
1	-	-	-	ERR
2	-	-	-	ERR
3	-	-	-	ERR
4	-	-	-	ERR
5	-	-	-	-
Avg.	0.000	0.000	0	ERR
Std. dev.	0.000	0.000	0	ERR
Coef of var.	ERR	ERR	ERR	ERR

name

Sample	thickness	width	Load	sig_c
1	-	-	-	ERR
2	-	-	-	ERR
3	-	-	-	ERR
4	-	-	-	ERR
5	-	-	-	ERR
Avg.	0.000	0.000	0	ERR
Std. dev.	0.000	0.000	0	ERR
Coef of var.	ERR	ERR	ERR	ERR

name

Sample	thickness	width	Load	sig_c
1	-	-	-	ERR
2	-	-	-	ERR
3	-	-	-	ERR
4	-	-	-	ERR
5	-	-	-	ERR
Avg.	0.000	0.000	0	ERR
Std. dev.	0.000	0.000	0	ERR
Coef of var.	ERR	ERR	ERR	ERR

name

Sample	thickness	width	Load	sig_c
1	-	-	-	ERR
2	-	-	-	ERR
3	-	-	-	ERR
4	-	-	-	ERR
5	-	-	-	ERR
Avg.	0.000	0.000	0	ERR
Std. dev.	0.000	0.000	0	ERR
Coef of var.	ERR	ERR	ERR	ERR

Table A.4. Raw data for ASTM D 638 tension test.

13-15oz Stitched Biax/8084

Sample	thickness	width	Load	sig_t
1	0.176	0.509	4707	52542.9
2	0.164	0.509	3642	43629.3
3	0.17	0.512	4338	49839.2
4	0.183	0.513	4460	47508.0
5	0.171	0.509	4957	56951.5
Avg.	0.173	0.510	4421	50094.2
Std. dev.	0.007	0.002	496	5039.0
Coef of var.	4.1%	0.4%	11.2%	10.1%

24oz WR/8510

Sample	thickness	width	Load	sig_t
1	0.148	0.513	4008	52789.6
2	0.15	0.515	3554	46006.5
3	0.149	0.514	4135	53991.6
4	0.151	0.51	4156	53967.0
5	0.15	0.51	3890	50849.7
Avg.	0.150	0.512	3949	51520.9
Std. dev.	0.001	0.002	245	3337.5
Coef of var.	0.8%	0.4%	6.2%	6.5%

8.9oz 7781/8084 (8H satin)

Sample	thickness	width	Load	sig_t
1	0.156	0.51	4280	53795.9
2	0.155	0.515	4519	56611.3
3	0.155	0.512	4709	59337.2
4	0.155	0.512	4606	58039.3
5	-	-	-	-
Avg.	0.155	0.512	4529	56945.9
Std. dev.	0.001	0.002	183	2376.9
Coef of var.	0.3%	0.4%	4.0%	4.2%

24oz WR/8520

Sample	thickness	width	Load	sig_t
1	0.149	0.51	4007	52730.6
2	0.14	0.51	3378	47310.9
3	0.145	0.51	3396	45922.9
4	0.145	0.509	3593	48682.3
5	0.152	0.51	-	0.0
Avg.	0.145	0.510	3594	48661.7
Std. dev.	0.004	0.001	292	2937.2
Coef of var.	2.5%	0.1%	8.1%	6.0%

24oz twill/8084

Sample	thickness	width	Load	sig_t
1	0.148	0.509	3815	50642.5
2	0.147	0.509	3416	45654.4
3	0.15	0.509	4387	57459.1
4	0.153	0.511	-	0.0
5	0.154	0.509	-	0.0
Avg.	0.148	0.509	3873	51252.0
Std. dev.	0.002	0.000	488	5925.9
Coef of var.	1.0%	0.0%	12.6%	11.6%

24 oz WR/Tactix 123

Sample	thickness	width	Load	sig_t
1	-	-	-	-
2	-	-	-	-
3	-	-	-	-
4	-	-	-	-
5	-	-	-	-
Avg.	0.000	0.000	0	0.0
Std. dev.	0.000	0.000	0	0.0
Coef of var.	-	-	-	-

24 oz WR/8084

Sample	thickness	width	Load	sig_t
1	0.137	0.509	3835	54995.5
2	0.135	0.509	3682	53583.6
3	0.143	0.513	3761	51268.4
4	0.146	0.511	3917	52502.5
5	0.139	0.51	3240	45704.6
Avg.	0.140	0.510	3687	51610.9
Std. dev.	0.004	0.002	265	3575.7
Coef of var.	3.2%	0.3%	7.2%	6.9%

9.6oz twill/8084

Sample	thickness	width	Load	sig_t
1	0.156	0.509	4247	53486.0
2	0.155	0.51	4248	53738.1
3	0.154	0.515	3957	49892.8
4	0.156	0.509	4535	57113.0
5	-	-	-	-
Avg.	0.155	0.511	4247	53557.5
Std. dev.	0.001	0.003	236	2950.1
Coef of var.	0.6%	0.6%	5.6%	5.5%

G:K900(50%)/8084

Sample	thickness	width	Load	sig_t
1	0.133	0.495	3840	58327.6
2	0.133	0.494	3855	58674.0
3	0.137	0.489	3762	56155.1
4	0.135	0.485	3713	56708.7
5	0.137	0.493	-	0.0
Avg.	0.135	0.491	3793	57466.4
Std. dev.	0.002	0.005	67	1223.9
Coef of var.	1.4%	0.9%	1.8%	2.1%

800gm (28oz) Chomarat/8084

Sample	thickness	width	Load	sig_t
1	0.202	0.509	3781	36773.7
2	0.177	0.51	3795	42040.5
3	0.182	0.518	3964	42046.8
4	0.184	0.517	3931	41323.3
5	0.192	0.51	3810	38909.3
Avg.	0.187	0.513	3856	40218.7
Std. dev.	0.010	0.004	85	2316.4
Coef of var.	5.2%	0.8%	2.2%	5.8%

Table A.4. (Continued)

10.9oz C1029(AS4W)/8084

Sample	thickness	width	Load	sig_t
1	0.159	0.515	8260	100873.2
2	0.159	0.518	7850	95310.9
3	0.158	0.517	7980	97691.2
4	0.158	0.517	-	0.0
5	-	-	-	-
Avg.	0.159	0.517	8030	97958.4
Std. dev.	0.001	0.002	210	2790.7
Coef of var.	0.4%	0.3%	2.6%	2.8%

9.6 Twill/C1029/8084

Sample	thickness	width	Load	sig_t
1	0.177	0.494	6000	68620.1
2	0.177	0.489	6090	70361.5
3	0.177	0.489	6398	73920.0
4	0.176	0.491	6177	71479.8
5	-	-	-	-
Avg.	0.177	0.491	6166	71095.4
Std. dev.	0.001	0.002	171	2220.5
Coef of var.	0.3%	0.5%	2.8%	3.1%

G:K900(40%)/8084

Sample	thickness	width	Load	sig_t
1	-	-	-	
2	-	-	-	-
3	-	-	-	-
4	-	-	-	-
5	-	-	-	-
Avg.	0.000	0.000	0	0.0
Std. dev.	0.000	0.000	0	0.0
Coef of var.	-	-	-	-

9.6oz Twill/C1059/8084

Sample	thickness	width	Load	sig_t
1	0.161	0.495	5213	65411.9
2	0.162	0.495	5218	65070.5
3	0.161	0.492	5042	63652.0
4	0.162	0.494	5011	62615.6
5	-	-	-	-
Avg.	0.162	0.494	5121	64187.5
Std. dev.	0.001	0.001	110	1295.7
Coef of var.	0.4%	0.3%	2.1%	2.0%

9.6oz Twill/SPECTRA(40%)/8084

Sample	thickness	width	Load	sig_t
1	0.133	0.519	3863	55963.6
2	0.132	0.519	3395	49556.3
3	0.135	0.521	3454	49107.8
4	0.131	0.522	3507	51285.4
5	-	-	-	-
Avg.	0.133	0.520	3555	51478.3
Std. dev.	0.002	0.002	211	3134.1
Coef of var.	1.3%	0.3%	5.9%	6.1%

9.6oz Twill/KEVLAR(60%)/8084

Sample	thickness	width	Load	sig_t
1	-	-	-	-
2	-	-	-	-
3	-	-	-	-
4	-	-	-	-
5	-	-	-	-
Avg.	0.000	0.000	0	0.0
Std. dev.	0.000	0.000	0	0.0
Coef of var.	-	-	-	-

Kevlar 900/8084

Sample	thickness	width	Load	sig_t
1	0.171	1.009	11620	67347.1
2	0.174	1	11800	67816.1
3	0.17	1.011	11950	69529.3
4	0.171	1.009	12750	73896.3
5	-	-	-	-
Avg.	0.172	1.007	12030	69647.2
Std. dev.	0.002	0.005	499	2984.0
Coef of var.	1.0%	0.5%	4.1%	4.3%

DF1400(warp)/8084

Sample	thickness	width	Load	sig_t
1	0.253	0.514	4552	35004.1
2	0.252	0.52	4412	33669.1
3	0.266	0.518	4561	33101.6
4	0.252	0.52	4663	35584.6
5	0.245	0.518	4794	37774.8
Avg.	0.254	0.518	4596	35026.8
Std. dev.	0.008	0.002	142	1831.2
Coef of var.	3.0%	0.5%	3.1%	5.2%

C1059(XASg)/8084

Sample	thickness	width	Load	sig_t
1	-	-	-	-
2	-	-	-	-
3	-	-	-	-
4	-	-	-	-
5	-	-	-	-
Avg.	0.000	0.000	0	0.0
Std. dev.	0.000	0.000	0	0.0
Coef of var.	-	-	-	-

C1029(UC309)/8084

Sample	thickness	width	Load	sig_t
1	-	-	-	-
2	-	-	-	-
3	-	-	-	-
4	-	-	-	-
5	-	-	-	-
Avg.	0.000	0.000	0	0.0
Std. dev.	0.000	0.000	0	0.0
Coef of var.	-	-	-	-

Table A.4. (Continued)

Spectra(985)/8084

Sample	thickness	width	Load	sig_t
1	-	-	-	-
2	-	-	-	-
3	-	-	-	-
4	-	-	-	-
5	-	-	-	-
Avg.	0.000	0.000	0	0.0
Std. dev.	0.000	0.000	0	0.0
Coef of var.	-	-	-	-

DF1400(fill)/8084

Sample	thickness	width	Load	sig_t
1	0.255	0.478	5668	46500.9
2	0.263	0.51	6660	49653.3
3	0.253	0.506	5920	46243.5
4	0.26	0.507	6350	48171.7
5	0.261	0.507	5990	45266.7
Avg.	0.258	0.502	6118	47167.2
Std. dev.	0.004	0.013	389	1739.2
Coef of var.	1.6%	2.6%	6.4%	3.7%

24 oz WR/8472

Sample	thickness	width	Load	sig_t
1	0.156	0.517	3322	41189.3
2	0.142	0.515	3468	47422.4
3	0.15	0.512	3125	40690.1
4	0.141	0.515	3788	52165.5
5	0.145	0.51	3092	41812.0
Avg.	0.147	0.514	3359	44655.9
Std. dev.	0.006	0.003	284	4997.0
Coef of var.	4.2%	0.5%	8.5%	11.2%

C1059(XASg)/9405

Sample	thickness	width	Load	sig_t
1	0.125	0.516	5794	89829.5
2	0.128	0.508	5511	84753.3
3	0.127	0.507	6140	95357.9
4	0.125	0.509	5120	80471.5
5	0.126	0.511	6150	95517.7
Avg.	0.126	0.510	5743	89186.0
Std. dev.	0.001	0.004	438	6599.0
Coef of var.	1.0%	0.7%	7.6%	7.4%

24 oz WR/510A

Sample	thickness	width	Load	sig_t
1	0.15	0.504	4481	59272.5
2	0.151	0.505	4265	55930.8
3	0.15	0.502	4216	55989.4
4	-	-	-	-
5	-	-	-	-
Avg.	0.150	0.504	4321	57064.2
Std. dev.	0.001	0.002	141	1912.7
Coef of var.	0.4%	0.3%	3.3%	3.4%

C1030/9405

Sample	thickness	width	Load	sig_t
1	0.118	0.492	-	0.0
2	0.114	0.492	-	0.0
3	0.118	0.494	-	0.0
4	0.118	0.5	5030	85254.2
5	0.117	0.497	5870	100947.6
Avg.	0.118	0.499	5450	93100.9
Std. dev.	0.001	0.002	594	11096.9
Coef of var.	0.6%	0.4%	10.9%	11.9%

name

Sample	thickness	width	Load	sig_t
1	-	-	-	ERR
2	-	-	-	ERR
3	-	-	-	ERR
4	-	-	-	ERR
5	-	-	-	ERR
Avg.	0.000	0.000	0	ERR
Std. dev.	0.000	0.000	0	ERR
Coef of var.	ERR	ERR	ERR	ERR

name

Sample	thickness	width	Load	sig_t
1	-	-	-	ERR
2	-	-	-	ERR
3	-	-	-	ERR
4	-	-	-	ERR
5	-	-	-	ERR
Avg.	0.000	0.000	0	ERR
Std. dev.	0.000	0.000	0	ERR
Coef of var.	ERR	ERR	ERR	ERR

name

Sample	thickness	width	Load	sig_t
1	-	-	-	ERR
2	-	-	-	ERR
3	-	-	-	ERR
4	-	-	-	ERR
5	-	-		ERR
Avg.	0.000	0.000	0	ERR
Std. dev.	0.000	0.000	0	ERR
Coef of var.	ERR	ERR	ERR	ERR

name

Sample	thickness	width	Load	sig_t
1	-	-	-	ERR
2	-	-	-	ERR
3	-	-	-	ERR
4	-	-	-	ERR
5	-	-	-	ERR
Avg.	0.000	0.000	0	ERR
Std. dev.	0.000	0.000	0	ERR
Coef of var.	ERR	ERR	ERR	ERR

Table A.5. Raw data for ASTM D 638 modulus test.

13-15oz Stitched Biax/8084

Sample	modulus
1	2.7005
2	2.5791
3	3.826
4	3.4954
5	3.2913
Avg.	3.178
Std. dev.	0.529
Coef of var.	16.6%

24oz WR/8510

Sample	modulus
1	4
2	4
3	4
4	3.8
5	3.7
Avg.	3.900
Std. dev.	0.141
Coef of var.	3.6%

8.9oz 7781/8084 (8H satin)

Sample	modulus
1	3.4
2	3.5
3	3.4
4	3.4
5	-
Avg.	3.425
Std. dev.	0.050
Coef of var.	1.5%

24oz WR/8520

Sample	modulus
1	3.6038
2	4.6027
3	4.5119
4	3.7625
5	3.1929
Avg.	3.935
Std. dev.	0.606
Coef of var.	15.4%

24oz twill/8084

Sample	modulus
1	3.0027
2	4.0224
3	2.5148
4	2.6286
5	3.1355
Avg.	3.061
Std. dev.	0.596
Coef of var.	19.5%

24 oz WR/Tactix 123

Sample	modulus
1	-
2	-
3	-
4	-
5	-
Avg.	0.000
Std. dev.	0.000
Coef of var.	-

24 oz WR/8084

Sample	modulus
1	3.5748
2	3.8934
3	3.7208
4	3.3827
5	3.1442
Avg.	3.543
Std. dev.	0.292
Coef of var.	8.2%

9.6oz twill/8084

Sample	modulus
1	-
2	3.7
3	3.3
4	3.3
5	-
Avg.	3.433
Std. dev.	0.231
Coef of var.	6.7%

G:K900(50%)/8084

Sample	modulus
1	3.884
2	3.8145
3	3.508
4	3.695
5	3.5
Avg.	3.680
Std. dev.	0.175
Coef of var.	4.7%

800gm (28oz) Chomarat/8084

Sample	modulus
1	2.6504
2	2.6274
3	3.6497
4	2.8871
5	2.8666
Avg.	2.936
Std. dev.	0.416
Coef of var.	14.2%

Table A.5. (Continued)

10.9oz C1029(AS4W)/8084

Sample	modulus
1	8.3
2	8.3
3	8.3
4	-
5	-
Avg.	8.300
Std. dev.	0.000
Coef of var.	0.0%

9.6 Twill/C1029/8084

Sample	modulus
1	6.106
2	6.254
3	6.305
4	7.027
5	-
Avg.	6.423
Std. dev.	0.411
Coef of var.	6.4%

G:K900(40%)/8084

Sample	modulus
1	-
2	-
3	-
4	-
5	-
Avg.	0.000
Std. dev.	0.000
Coef of var.	-

9.6oz Twill/C1059/8084

Sample	modulus
1	5.612
2	5.718
3	6.209
4	6.659
5	-
Avg.	6.050
Std. dev.	0.482
Coef of var.	8.0%

9.6oz Twill/SPECTRA(40%)/8084

Sample	modulus
1	-
2	3
3	3.3
4	3.1
5	-
Avg.	3.133
Std. dev.	0.153
Coef of var.	4.9%

9.6oz Twill/KEVLAR(60%)/8084

Sample	modulus
1	-
2	-
3	-
4	-
5	-
Avg.	0.000
Std. dev.	0.000
Coef of var.	-

Kevlar 900/8084

Sample	modulus
1	4.1395
2	4.2016
3	4.182
4	4.693
5	-
Avg.	4.304
Std. dev.	0.261
Coef of var.	6.1%

DF1400(warp)/8084

Sample	modulus
1	5.3671
2	5.0077
3	3.4791
4	2.3722
5	3.1595
Avg.	3.877
Std. dev.	1.269
Coef of var.	32.7%

C1059(XASg)/8084

Sample	modulus
1	7.8
2	7.6
3	8.1
4	8.1
5	-
Avg.	7.900
Std. dev.	0.245
Coef of var.	-

C1029(UC309)/8084

Sample	modulus
1	-
2	-
3	-
4	-
5	-
Avg.	0.000
Std. dev.	0.000
Coef of var.	-

Table A.5. (Continued)

Spectra(985)/8084

Sample	modulus
1	1.86
2	2.4
3	-
4	-
5	-
Avg.	2.130
Std. dev.	0.382
Coef of var.	17.9%

DF1400(fill)/8084

Sample	modulus
1	3.1
2	3.4
3	4
4	3.5
5	3.2
Avg.	3.440
Std. dev.	0.351
Coef of var.	10.2%

24 oz WR/8472

Sample	modulus
1	3.4846
2	3.8854
3	3.4776
4	3.7537
5	3.4672
Avg.	3.614
Std. dev.	0.194
Coef of var.	5.4%

C1059(XASg)/9405

Sample	modulus
1	8.6
2	8
3	8.4
4	-
5	-
Avg.	8.333
Std. dev.	0.306
Coef of var.	3.7%

24 oz WR/510A

Sample	modulus
1	3.6
2	3.6
3	3.9
4	-
5	-
Avg.	3.700
Std. dev.	0.173
Coef of var.	4.7%

C1030/9405

Sample	modulus
1	8.8
2	8.6
3	8.2
4	8.4
5	8.5
Avg.	8.500
Std. dev.	0.224
Coef of var.	2.6%

name

Sample	modulus
1	-
2	-
3	-
4	-
5	-
Avg.	0.000
Std. dev.	0.000
Coef of var.	ERR

name

Sample	modulus
1	-
2	-
3	-
4	-
5	-
Avg.	0.000
Std. dev.	0.000
Coef of var.	ERR

name

Sample	modulus
1	-
2	-
3	-
4	-
5	-
Avg.	0.000
Std. dev.	0.000
Coef of var.	ERR

name

Sample	modulus
1	-
2	-
3	-
4	-
5	-
Avg.	0.000
Std. dev.	0.000
Coef of var.	ERR

Table A.6. Raw data for ASTM D 790 flexure test.

13-15oz Stitched Biax/8084			span=	4.5
Sample	thickness	width	Load	sig_b
1	0.177	0.505	129	55037.1
2	0.174	0.504	131	57949.0
3	0.182	0.503	156	63200.1
4	0.177	0.504	146	62413.6
5	0.174	0.509	137	60007.8
Avg.	0.177	0.505	140	59721.5
Std. dev.	0.003	0.002	11	3336.0
Coef of var.	1.9%	0.5%	8.0%	5.6%

24oz WR/8510			span=	4.5
Sample	thickness	width	Load	sig_b
1	0.151	0.502	91	53664.6
2	0.153	0.504	99	56640.3
3	0.156	0.507	102	55801.6
4	0.152	0.504	102	59127.1
5	0.157	0.499	91	49939.6
Avg.	0.154	0.503	97	55034.6
Std. dev.	0.003	0.003	6	3455.1
Coef of var.	1.7%	0.6%	5.8%	6.3%

8.9oz 7781/8084 (8H satin)			span=	4.5
Sample	thickness	width	Load	sig_b
1	0.152	0.505	147	85043.8
2	0.151	0.504	139	81645.9
3	0.152	0.508	141	81090.9
4	0.15	0.504	139	82738.1
5	0.152	0.502	150	87298.0
Avg.	0.151	0.505	143	83563.3
Std. dev.	0.001	0.002	5	2579.2
Coef of var.	0.6%	0.4%	3.5%	3.1%

24oz WR/8520			span=	4.5
Sample	thickness	width	Load	sig_b
1	0.148	0.502	107	65684.1
2	0.148	0.505	104	63463.2
3	0.147	0.503	82	50923.1
4	0.148	0.501	88	54128.4
5	0.146	0.501	90	56885.7
Avg.	0.147	0.502	94	58216.9
Std. dev.	0.001	0.002	11	6224.4
Coef of var.	0.6%	0.3%	11.4%	10.7%

24oz twill/8084			span=	4.5
Sample	thickness	width	Load	sig_b
1	0.157	0.497	145	79894.4
2	0.158	0.507	129	68797.3
3	0.157	0.501	155	84722.4
4	0.156	0.504	150	82549.7
5	0.159	0.495	147	79290.6
Avg.	0.157	0.501	145	79050.9
Std. dev.	0.001	0.005	10	6130.1
Coef of var.	0.7%	1.0%	6.8%	7.8%

24 oz WR/Tactix 123			span=	4.5
Sample	thickness	width	Load	sig_b
1	0.154	0.504	114	64377.9
2	0.156	0.503	117	64516.7
3	0.15	0.503	140	83499.0
4	0.148	0.502	116	71209.0
5	0.155	0.505	125	69543.9
Avg.	0.153	0.503	122	70629.3
Std. dev.	0.003	0.001	11	7803.6
Coef of var.	2.3%	0.2%	8.7%	11.0%

24 oz WR/8084			span=	4.5
Sample	thickness	width	Load	sig_b
1	0.145	0.501	110	70489.2
2	0.145	0.5	120	77051.1
3	0.145	0.506	104	65985.8
4	0.144	0.504	118	76213.2
5	0.144	0.5	107	69661.5
Avg.	0.145	0.502	112	71880.2
Std. dev.	0.001	0.003	7	4666.8
Coef of var.	0.4%	0.5%	6.2%	6.5%

9.6oz twill/8084			span=	4.5
Sample	thickness	width	Load	sig_b
1	0.151	0.505	134	78553.1
2	0.152	0.512	130	74180.5
3	0.149	0.511	128	76158.8
4	0.15	0.505	128	76039.6
5	0.154	0.502	139	78808.6
Avg.	0.151	0.507	132	76748.1
Std. dev.	0.002	0.004	5	1932.9
Coef of var.	1.3%	0.8%	3.6%	2.5%

G:K900(50%)/8084			span=	4.5
Sample	thickness	width	Load	sig_b
1	0.114	0.515	61	61520.0
2	0.114	0.516	62	62407.4
3	0.114	0.516	62	62407.4
4	0.117	0.514	65	62356.6
5	0.116	0.514	66	64412.3
Avg.	0.115	0.515	63	62620.7
Std. dev.	0.001	0.001	2	1070.3
Coef of var.	1.2%	0.2%	3.4%	1.7%

800gm (28oz) Chomarat/8084			span=	4.5
Sample	thickness	width	Load	sig_b
1	0.187	0.499	195	75431.8
2	0.186	0.5	189	73751.3
3	0.189	0.504	175	65612.7
4	0.188	0.503	179	67963.1
5	0.182	0.502	157	63731.9
Avg.	0.186	0.502	179	69298.2
Std. dev.	0.003	0.002	15	5094.1
Coef of var.	1.4%	0.4%	8.2%	7.4%

Table A.6. (Continued)

10.9oz C1029(AS4W)/8084

Sample	thickness	width	Load	sig_b
			span=	4.5
1	0.159	0.507	140	73727.5
2	0.159	0.504	129	68339.0
3	0.157	0.503	134	72952.7
4	0.158	0.506	119	63589.6
5	0.159	0.505	132	69789.8
Avg.	0.158	0.505	131	69679.7
Std. dev.	0.001	0.002	8	4061.9
Coef of var.	0.6%	0.3%	5.9%	5.8%

9.6 twill/10.9 C1029/8084

Sample	thickness	width	Load	sig_b
			span=	4.5
1	0.17	0.5	210	98096.9
2	0.173	0.5	206	92919.9
3	0.17	0.501	211	98367.3
4	0.171	0.499	208	96222.0
5	0.172	0.503	214	97071.7
Avg.	0.171	0.501	210	96535.6
Std. dev.	0.001	0.002	3	2193.8
Coef of var.	0.8%	0.3%	1.4%	2.3%

G:K900(40%)/8084

Sample	thickness	width	Load	sig_b
			span=	4.5
1	0.13	0.51	93	72833.3
2	0.132	0.512	100	75663.4
3	0.127	0.51	93	76314.9
4	0.134	0.511	97	71358.4
5	0.13	0.532	98	73575.2
Avg.	0.131	0.515	96	73949.0
Std. dev.	0.003	0.010	3	2039.1
Coef of var.	2.0%	1.9%	3.2%	2.8%

9.6oz Twill/C1059/8084

Sample	thickness	width	Load	sig_b
			span=	4.5
1	0.16	0.503	201	105363.9
2	0.158	0.504	171	91739.2
3	0.158	0.503	190	102135.1
4	0.161	0.5	199	103641.8
5	0.159	0.502	176	93609.2
Avg.	0.159	0.502	187	99297.9
Std. dev.	0.001	0.002	13	6188.9
Coef of var.	0.8%	0.3%	7.2%	6.2%

9.6oz Twill/SPECTRA(40%)/8084

Sample	thickness	width	Load	sig_b
			span=	4.5
1	0.129	0.509	102	81284.3
2	0.13	0.51	99	77532.2
3	0.131	0.51	98	75581.8
4	0.13	0.508	107	84127.3
5	0.128	0.507	91	73946.4
Avg.	0.130	0.509	99	78494.4
Std. dev.	0.001	0.001	6	4171.5
Coef of var.	0.9%	0.3%	5.9%	5.3%

9.6oz Twill/KEVLAR(60%)/8084

Sample	thickness	width	Load	sig_b
			span=	4.5
1	0.19	0.506	192	70949.2
2	0.19	0.507	213	78554.0
3	0.186	0.506	198	76347.1
4	0.188	0.504	198	75027.9
5	0.186	0.506	198	76347.1
Avg.	0.188	0.506	200	75445.0
Std. dev.	0.002	0.001	8	2814.2
Coef of var.	1.1%	0.2%	3.9%	3.7%

Kevlar 900/8084

Sample	thickness	width	Load	sig_b
			span=	4.5
1	0.168	0.505	70	33150.6
2	0.166	0.511	78	37390.5
3	0.168	0.505	77	36465.7
4	0.169	0.504	75	35169.1
5	-	-	-	-
Avg.	0.168	0.506	75	35544.0
Std. dev.	0.001	0.003	4	1837.4
Coef of var.	0.8%	0.6%	4.7%	5.2%

DF1400(warp)/8084

Sample	thickness	width	Load	sig_b
			span=	5
1	0.243	0.507	183	45845.0
2	0.258	0.507	203	45113.9
3	0.244	0.506	186	46306.7
4	0.25	0.506	209	49565.2
5	0.252	0.516	193	44174.1
Avg.	0.249	0.508	195	46201.0
Std. dev.	0.006	0.004	11	2046.1
Coef of var.	2.5%	0.8%	5.7%	4.4%

C1059(XASg)/8084

Sample	thickness	width	Load	sig_b
			span=	4.5
1	0.177	0.504	154	65833.6
2	0.18	0.501	132	54890.2
3	0.179	0.502	152	63787.8
4	0.18	0.503	144	59642.1
5	0.18	0.504	138	57043.7
Avg.	0.179	0.503	144	60239.5
Std. dev.	0.001	0.001	9	4557.1
Coef of var.	0.7%	0.3%	6.4%	7.6%

C1029(UC309)/8084

Sample	thickness	width	Load	sig_b
			span=	4.5
1	0.161	0.495	124	65233.2
2	0.16	0.502	143	75109.7
3	0.159	0.503	131	69536.5
4	0.16	0.503	121	63428.0
5	0.159	0.501	127	67682.4
Avg.	0.160	0.501	129	68198.0
Std. dev.	0.001	0.003	9	4510.3
Coef of var.	0.5%	0.7%	6.6%	6.6%

Table A.6. (Continued)

Spectra(985)/8084			span=	4.5
Sample	thickness	width	Load	sig_b
1	0.116	0.509	18	17739.5
2	0.115	0.509	19	19052.1
3	0.115	0.509	19	19052.1
4	0.116	0.508	19	18761.9
5	0.116	0.51	18	17704.8
Avg.	0.116	0.509	19	18462.1
Std. dev.	0.001	0.001	1	685.9
Coef of var.	0.5%	0.1%	2.9%	3.7%

24 oz WR/8472			span=	4.5
Sample	thickness	width	Load	sig_b
1	0.145	0.501	110	70489.2
2	0.145	0.5	120	77051.1
3	0.145	0.506	104	65985.8
4	0.144	0.504	118	76213.2
5	0.144	0.5	107	69661.5
Avg.	0.145	0.502	112	71880.2
Std. dev.	0.001	0.003	7	4666.8
Coef of var.	0.4%	0.5%	6.2%	6.5%

24 oz WR/510A			span=	4.5
Sample	thickness	width	Load	sig_b
1	0.152	0.51	136	77908.6
2	0.15	0.507	128	75739.6
3	0.148	0.509	134	81127.4
4	0.152	0.507	132	76064.6
5	0.15	0.508	147	86811.0
Avg.	0.150	0.508	135	79530.2
Std. dev.	0.002	0.001	7	4598.1
Coef of var.	1.1%	0.3%	5.3%	5.8%

name			span=	4.5
Sample	thickness	width	Load	sig_b
1	-	-	-	ERR
2	-	-	-	ERR
3	-	-	-	ERR
4	-	-	-	ERR
5	-	-	-	ERR
Avg.	0.000	0.000	0	ERR
Std. dev.	0.000	0.000	0	ERR
Coef of var.	ERR	ERR	ERR	ERR

name			span=	4.5
Sample	thickness	width	Load	sig_b
1	-	-	-	ERR
2	-	-	-	ERR
3	-	-	-	ERR
4	-	-	-	ERR
5	-	-	-	ERR
Avg.	0.000	0.000	0	ERR
Std. dev.	0.000	0.000	0	ERR
Coef of var.	ERR	ERR	ERR	ERR

DF1400(fill)/8084			span=	5
Sample	thickness	width	Load	sig_b
1	0.264	0.505	265	56468.7
2	0.257	0.505	289	64983.3
3	0.259	0.505	279	61769.6
4	0.26	0.504	280	61637.1
5	0.263	0.505	286	61407.9
Avg.	0.261	0.505	280	61253.3
Std. dev.	0.003	0.000	9	3051.3
Coef of var.	1.1%	0.1%	3.3%	5.0%

C1059(XASg)/9405			span=	4.5
Sample	thickness	width	Load	sig_b
1	0.127	0.508	118	97210.8
2	0.124	0.503	111	96875.8
3	0.13	0.507	133	104775.7
4	0.13	0.508	129	101424.5
5	-	-	-	-
Avg.	0.128	0.507	123	100071.7
Std. dev.	0.003	0.002	10	3757.5
Coef of var.	2.2%	0.5%	8.2%	3.8%

C1030/9405			span=	4.5
Sample	thickness	width	Load	sig_b
1	0.118	0.508	105	100199.5
2	0.118	0.507	104	99440.9
3	0.119	0.508	104	97584.2
4	0.117	0.506	104	101347.9
5	0.12	0.506	105	97270.3
Avg.	0.118	0.507	104	99168.6
Std. dev.	0.001	0.001	1	1732.1
Coef of var.	1.0%	0.2%	0.5%	1.7%

name			span=	4.5
Sample	thickness	width	Load	sig_b
1	-	-	-	ERR
2	-	-	-	ERR
3	-	-	-	ERR
4	-	-	-	ERR
5	-	-	-	ERR
Avg.	0.000	0.000	0	ERR
Std. dev.	0.000	0.000	0	ERR
Coef of var.	ERR	ERR	ERR	ERR

name			span=	4.5
Sample	thickness	width	Load	sig_b
1	-	-	-	ERR
2	-	-	-	ERR
3	-	-	-	ERR
4	-	-	-	ERR
5	-	-	-	ERR
Avg.	0.000	0.000	0	ERR
Std. dev.	0.000	0.000	0	ERR
Coef of var.	ERR	ERR	ERR	ERR

Table A.7. Raw data for ASTM D 2344 shear test.

13-15oz Stitched Biax/8084			span=	0.9
Sample	thickness	width	Load	tau
1	0.175	0.505	589	4998.6
2	0.178	0.505	526	4388.7
3	0.18	0.503	602	4986.7
4	0.177	0.5	600	5084.7
5	0.182	0.499	515	4253.0
Avg.	0.178	0.502	566	4742.4
Std. dev.	0.003	0.003	42	389.6
Coef of var.	1.5%	0.6%	7.5%	8.2%

24oz WR/8510			span=	0.9
Sample	thickness	width	Load	tau
1	0.152	0.502	503	4944.0
2	0.148	0.499	489	4966.0
3	0.148	0.502	536	5410.8
4	0.148	0.501	513	5188.9
5	0.152	0.497	495	4914.4
Avg.	0.150	0.500	507	5084.8
Std. dev.	0.002	0.002	18	212.2
Coef of var.	1.5%	0.4%	3.6%	4.2%

8.9oz 7781/8084 (8H satin)			span=	0.9
Sample	thickness	width	Load	tau
1	0.152	0.504	730	7146.8
2	0.153	0.502	738	7206.5
3	0.153	0.504	729	7090.3
4	0.152	0.504	720	7048.9
5	0.152	0.503	731	7170.8
Avg.	0.152	0.503	730	7132.6
Std. dev.	0.001	0.001	6	63.1
Coef of var.	0.4%	0.2%	0.9%	0.9%

24oz WR/8520			span=	0.9
Sample	thickness	width	Load	tau
1	0.155	0.504	426	4089.9
2	0.151	0.511	408	3965.7
3	0.153	0.502	423	4130.5
4	0.152	0.503	438	4296.6
5	0.153	0.503	471	4590.1
Avg.	0.153	0.505	433	4214.6
Std. dev.	0.001	0.004	24	241.0
Coef of var.	1.0%	0.7%	5.5%	5.7%

24oz twill/8084			span=	0.9
Sample	thickness	width	Load	tau
1	0.16	0.504	615	5719.9
2	0.157	0.5	612	5847.1
3	0.162	0.51	601	5455.7
4	0.156	0.505	586	5578.8
5	0.162	0.505	625	5729.7
Avg.	0.159	0.505	608	5666.3
Std. dev.	0.003	0.004	15	151.3
Coef of var.	1.8%	0.7%	2.4%	2.7%

24 oz WR/Tactix 123			span=	0.9
Sample	thickness	width	Load	tau
1	0.157	0.499	490	4690.9
2	0.15	0.507	553	5453.6
3	0.154	0.455	453	4848.7
4	0.151	0.505	509	5006.2
5	0.15	0.502	535	5328.7
Avg.	0.152	0.494	508	5065.6
Std. dev.	0.003	0.022	39	320.4
Coef of var.	2.0%	4.4%	7.7%	6.3%

24 oz WR/8084			span=	0.9
Sample	thickness	width	Load	tau
1	0.146	0.497	518	5354.0
2	0.145	0.502	536	5522.7
3	0.145	0.5	534	5524.1
4	0.145	0.5	486	5027.6
5	0.146	0.498	507	5229.8
Avg.	0.145	0.499	516	5331.7
Std. dev.	0.001	0.002	21	210.3
Coef of var.	0.4%	0.4%	4.0%	3.9%

9.6oz twill/8084			span=	0.9
Sample	thickness	width	Load	tau
1	0.157	0.501	520	4958.2
2	0.15	0.501	541	5399.2
3	0.156	0.499	497	4788.4
4	0.157	0.501	503	4796.1
5	0.156	0.5	483	4644.2
Avg.	0.155	0.500	509	4917.2
Std. dev.	0.003	0.001	22	291.4
Coef of var.	1.9%	0.2%	4.4%	5.9%

G:K900(50%)/8084			span=	0.9
Sample	thickness	width	Load	tau
1	-	-	-	-
2	-	-	-	-
3	-	-	-	-
4	-	-	-	-
5	-	-	-	-
Avg.	0.000	0.000	0	0.0
Std. dev.	0.000	0.000	0	0.0
Coef of var.	-	-	-	-

800gm (28oz) Chomarat/8084			span=	0.9
Sample	thickness	width	Load	tau
1	0.185	0.502	790	6379.9
2	0.185	0.498	768	6252.0
3	0.185	0.499	719	5841.4
4	0.187	0.499	793	6373.7
5	0.183	0.499	757	6217.4
Avg.	0.185	0.499	765	6212.9
Std. dev.	0.001	0.002	30	219.8
Coef of var.	0.8%	0.3%	3.9%	3.5%

Table A.7. (Continued)

10.9oz C1029(AS4W)/8084			span=	0.9
Sample	thickness	width	Load	tau
1	0.158	0.502	515	4869.8
2	0.157	0.503	535	5081.0
3	0.158	0.503	529	4992.2
4	0.157	0.507	522	4918.4
5	0.159	0.44	443	4749.1
Avg.	0.158	0.491	509	4922.1
Std. dev.	0.001	0.029	38	125.3
Coef of var.	0.5%	5.8%	7.4%	2.5%

9.6oz twill/10.9 C1029/8084			span=	0.9
Sample	thickness	width	Load	tau
1	0.17	0.509	496	4299.1
2	0.175	0.505	512	4345.1
3	0.17	0.503	513	4499.5
4	0.171	0.508	509	4394.6
5	0.17	0.503	500	4385.5
Avg.	0.171	0.506	506	4384.7
Std. dev.	0.002	0.003	8	74.4
Coef of var.	1.3%	0.6%	1.5%	1.7%

G:K900(40%)/8084			span=	0.9
Sample	thickness	width	Load	tau
1	-	-	-	-
2	-	-	-	-
3	-	-	-	-
4	-	-	-	-
5	-	-	-	-
Avg.	0.000	0.000	0	0.0
Std. dev.	0.000	0.000	0	0.0
Coef of var.	-	-	-	-

9.6oz Twill/C1059/8084			span=	0.9
Sample	thickness	width	Load	tau
1	0.162	0.5	458	4240.7
2	0.161	0.504	461	4260.9
3	0.161	0.503	457	4232.4
4	0.165	0.501	488	4427.5
5	0.162	0.502	478	4408.3
Avg.	0.162	0.502	468	4314.0
Std. dev.	0.002	0.002	14	95.7
Coef of var.	1.0%	0.3%	3.0%	2.2%

9.6oz Twill/SPECTRA(40%)/8084			span=	0.9
Sample	thickness	width	Load	tau
1	0.129	0.51	275	3135.0
2	0.13	0.508	270	3066.3
3	0.132	0.504	266	2998.7
4	0.131	0.513	282	3147.2
5	0.129	0.51	281	3203.4
Avg.	0.130	0.509	275	3110.1
Std. dev.	0.001	0.003	7	79.1
Coef of var.	1.0%	0.7%	2.5%	2.5%

9.6oz Twill/KEVLAR(60%)/8084			span=	0.9
Sample	thickness	width	Load	tau
1	0.188	0.504	450	3561.9
2	0.186	0.504	464	3712.2
3	0.187	0.503	471	3755.5
4	0.184	0.504	471	3809.2
5	0.186	0.503	457	3663.5
Avg.	0.186	0.504	463	3700.5
Std. dev.	0.001	0.001	9	94.3
Coef of var.	0.8%	0.1%	2.0%	2.5%

Kevlar 900/8084			span=	0.9
Sample	thickness	width	Load	tau
1	0.169	0.514	274	2365.7
2	0.166	0.509	278	2467.6
3	0.167	0.505	276	2454.5
4	0.168	0.504	281	2489.0
5	-	-	-	-
Avg.	0.168	0.508	277	2444.2
Std. dev.	0.001	0.005	3	54.2
Coef of var.	0.8%	0.9%	1.1%	2.2%

DF1400(warp)/8084			span=	1.25
Sample	thickness	width	Load	tau
1	0.244	0.51	763	4598.6
2	0.245	0.511	738	4421.1
3	0.235	0.511	731	4565.5
4	0.245	0.507	857	5174.5
5	-	-	-	-
Avg.	0.242	0.510	772	4689.9
Std. dev.	0.005	0.002	58	332.1
Coef of var.	2.0%	0.4%	7.5%	7.1%

C1059(XASg)/8084			span=	0.9
Sample	thickness	width	Load	tau
1	0.183	0.5	569	4663.9
2	0.18	0.505	529	4364.7
3	0.18	0.505	534	4405.9
4	0.175	0.5	491	4208.6
5	0.183	0.503	562	4579.1
Avg.	0.180	0.503	537	4444.4
Std. dev.	0.003	0.003	31	180.1
Coef of var.	1.8%	0.5%	5.8%	4.1%

C1029(UC309)/8084			span=	0.9
Sample	thickness	width	Load	tau
1	0.158	0.502	515	4869.8
2	0.157	0.503	535	5081.0
3	0.158	0.503	529	4992.2
4	0.157	0.507	522	4918.4
5	0.157	0.44	443	4809.6
Avg.	0.157	0.491	509	4934.2
Std. dev.	0.001	0.029	38	105.9
Coef of var.	0.3%	5.8%	7.4%	2.1%

Table A.7. (Continued)

Spectra(985)/8084 span= 0.9

Sample	thickness	width	Load	tau
1	0.117	0.512	130	1627.6
2	0.115	0.51	125	1598.5
3	0.116	0.511	155	1961.2
4	0.115	0.51	139	1777.5
5	0.117	0.513	152	1899.3
Avg.	0.116	0.511	140	1772.8
Std. dev.	0.001	0.001	13	160.5
Coef of var.	0.9%	0.3%	9.4%	9.1%

DF1400(fill)/8084 span= 1.2

Sample	thickness	width	Load	tau
1	0.265	0.506	1010	5649.2
2	0.264	0.507	929	5205.5
3	0.272	0.507	1075	5846.5
4	0.262	0.506	974	5510.2
5	0.262	0.506	1002	5668.6
Avg.	0.265	0.506	998	5576.0
Std. dev.	0.004	0.001	53	239.1
Coef of var.	1.6%	0.1%	5.4%	4.3%

24 oz WR/8472 span= 0.9

Sample	thickness	width	Load	tau
1	0.149	0.509	346	3421.6
2	0.153	0.505	391	3795.4
3	0.151	0.505	348	3422.7
4	0.155	0.504	363	3485.0
5	-	-	-	-
Avg.	0.152	0.506	362	3531.2
Std. dev.	0.003	0.002	21	178.6
Coef of var.	1.7%	0.4%	5.7%	5.1%

C1059(XASg)/9405 span= 0.9

Sample	thickness	width	Load	tau
1	0.157	0.501	520	4958.2
2	0.15	0.501	541	5399.2
3	0.156	0.499	497	4788.4
4	0.157	0.501	503	4796.1
5	0.156	0.5	483	4644.2
Avg.	0.155	0.500	509	4917.2
Std. dev.	0.003	0.001	22	291.4
Coef of var.	1.9%	0.2%	4.4%	5.9%

24 oz WR/510A span= 0.9

Sample	thickness	width	Load	tau
1	0.153	0.506	612	5928.9
2	0.151	0.506	603	5919.0
3	0.151	0.504	582	5735.6
4	0.158	0.505	594	5583.4
5	-	-	-	-
Avg.	0.153	0.505	598	5791.7
Std. dev.	0.003	0.001	13	164.9
Coef of var.	2.2%	0.2%	2.1%	2.8%

C1030/9405 span= 0.9

Sample	thickness	width	Load	tau
1	0.116	0.51	382	4842.8
2	0.117	0.506	405	5130.7
3	0.114	0.51	361	4656.9
4	0.116	0.51	409	5185.1
5	-	-	-	-
Avg.	0.116	0.509	389	4953.9
Std. dev.	0.001	0.002	22	248.5
Coef of var.	1.1%	0.4%	5.7%	5.0%

name span= 0.9

Sample	thickness	width	Load	tau
1	-	-	-	ERR
2	-	-	-	ERR
3	-	-	-	ERR
4	-	-	-	ERR
5	-	-	-	ERR
Avg.	0.000	0.000	0	ERR
Std. dev.	0.000	0.000	0	ERR
Coef of	ERR	ERR	ERR	ERR

name span= 0.9

Sample	thickness	width	Load	tau
1	-	-	-	ERR
2	-	-	-	ERR
3	-	-	-	ERR
4	-	-	-	ERR
5	-	-	-	ERR
Avg.	0.000	0.000	0	ERR
Std. dev.	0.000	0.000	0	ERR
Coef of var.	ERR	ERR	ERR	ERR

name span= 0.9

Sample	thickness	width	Load	tau
1	-	-	-	ERR
2	-	-	-	ERR
3	-	-	-	ERR
4	-	-	-	ERR
5	-	-	-	ERR
Avg.	0.000	0.000	0	ERR
Std. dev.	0.000	0.000	0	ERR
Coef of var.	ERR	ERR	ERR	ERR

name span= 0.9

Sample	thickness	width	Load	tau
1	-	-	-	ERR
2	-	-	-	ERR
3	-	-	-	ERR
4	-	-	-	ERR
5	-	-	-	ERR
Avg.	0.000	0.000	0	ERR
Std. dev.	0.000	0.000	0	ERR
Coef of var.	ERR	ERR	ERR	ERR

REFERENCES

1. W. Seemann, U.S. Patent # 4,902,215.

2. P. Puckett, Dow Chemical, personal communication.

3. Hepburn, R.D., Magliulo, G., and Wright, T., "The U.S. Navy's New Coastal Minehunter (MHC): Design, Material, and Construction Facilities", Naval Engineers Journal, May 1991, page 66.

4. Palmer, R.J., "Investigation of the Effect of Resin Material on Impact Damage to Graphite/Epoxy Composites", NASA Contractor Report 165677, March 1981.

5. White, W.D., and Barron, J.H., "Vinyl Ester Resins for Military and Aerospace Applications", 34th International SAMPE Symposium, May 8-11, 1989.

6. Blankenship, L.T., White, M.N., and Puckett, P.M., "Vinyl Ester Resins-Versatile Resins for Composites"' 34th SAMPE Symposium, May 1989.

7. M. Russell, NSWC Norfolk Division, personal communication.

8. R. McCoy, U.S. Patent # 4,107,118.

9. Marchant, A., and Pinzelli, R.F., "Composites for Marine Structures. Where is the Future?", SAMPE Conf., Euro. Chpt., La Baule, France, May '87.

10. Tucker, W.C., Brown, R., and Russell, L., "Corrosion Between a Graphite/Polymer Composite and Metals", Journal of Composite Materials, Vol. 24, January 1990, Page 92.

11. Aylor, D. and Murray, J., "The Effect of Seawater Environment on the Galvanic Corrosion Behavior of Graphite/Epoxy Composites Coupled to Metals", CDNSWC-SME-92/32 August 1992.

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